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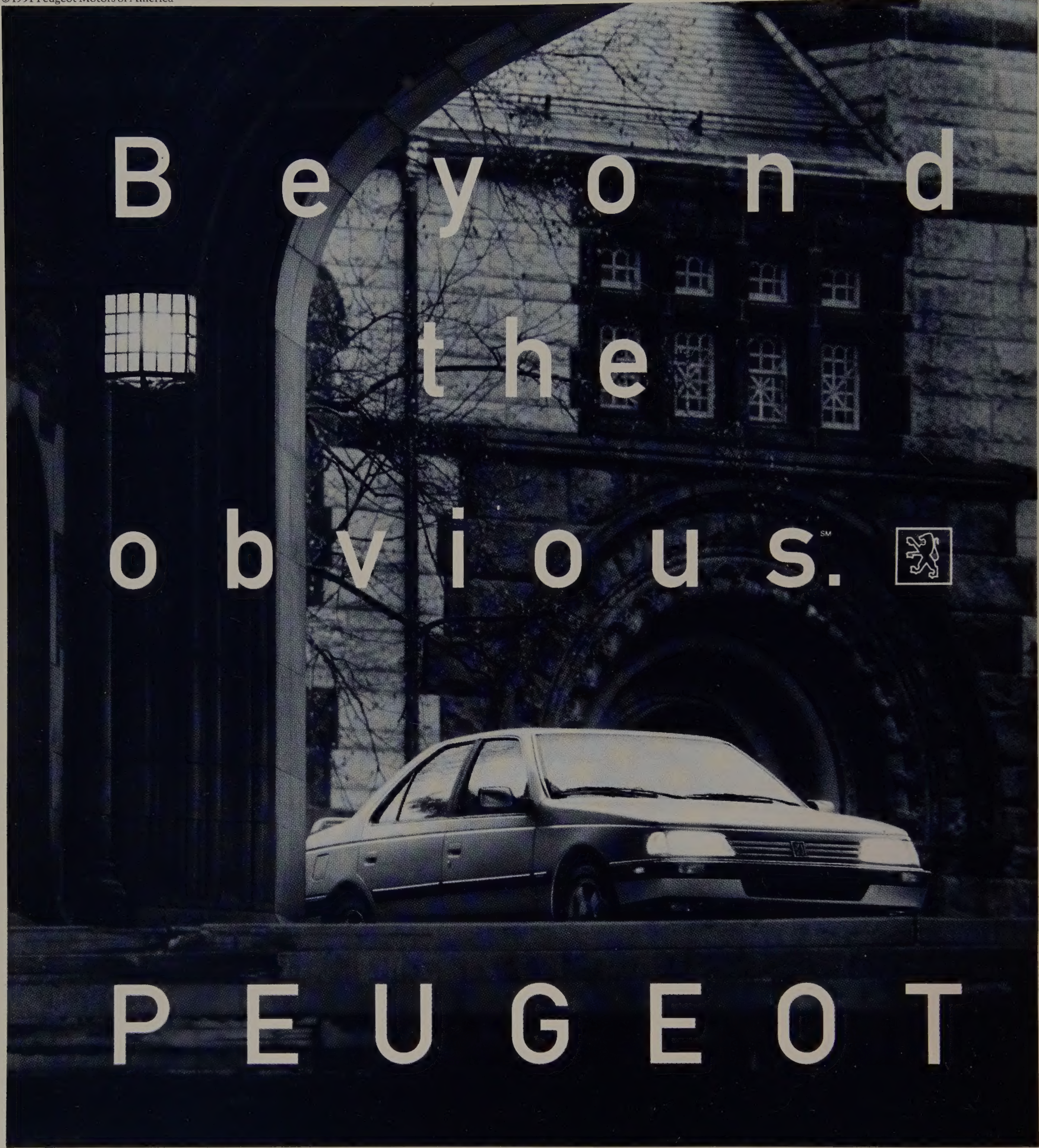


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# NATURAL HISTORY

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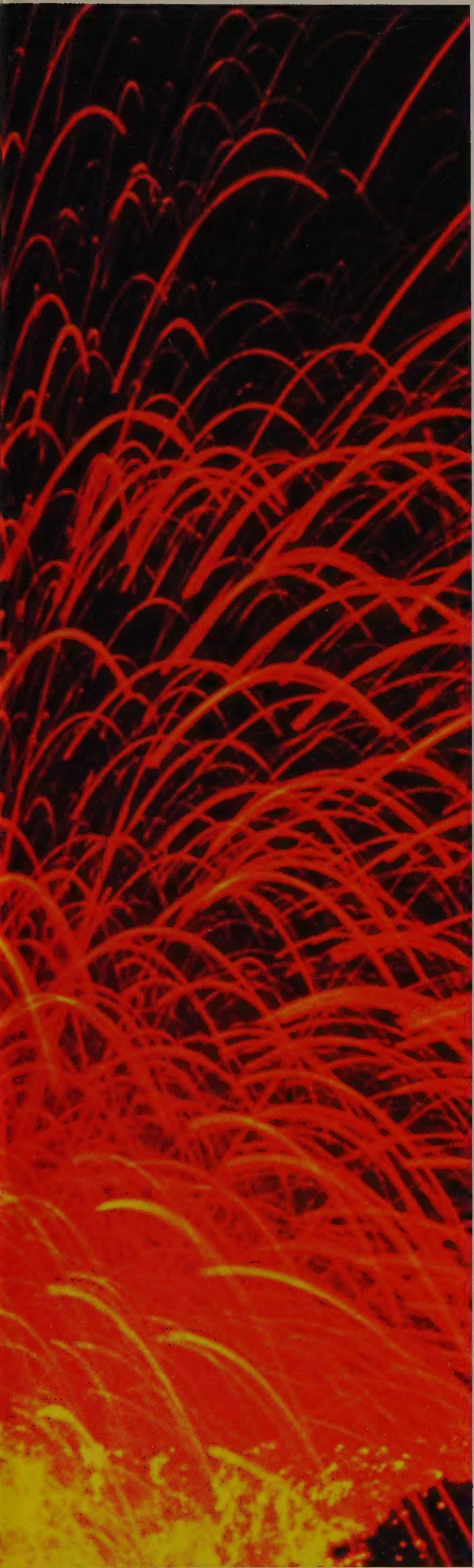

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COVER: *Lava bursts out of a rupture near Puu Oo, Hawaii. The largest eruptions of today are minor when compared with volcanic floods of the geologic past. Story on page 50. Photograph by Greg Vaughn.*



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# NATURAL HISTORY

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# LETTERS

## JUMBO SQUIRRELS

In the February 1991 issue on pages 6 and 8, Bernd Heinrich ("Nutcracker Sweets") cites a figure of 117,000 calories as the minimum daily energy requirement of a red squirrel. People on reducing diets are commonly told to keep their caloric intake below 2,000 calories per day, and I have read about an experiment in which soldiers in the far north were allowed to eat all they wanted, and they averaged about 5,000 calories per day in subzero weather.

Simple arithmetic with those figures would lead us to believe that one tiny little squirrel eats as much each day as 23.4 very hungry men! And that much is without a grain of salt; with a grain of salt we might ask if we're talking about the same kind of calories. Do squirrels eat millicalories, pehaps?

JOHN S. MERCHANT
*Eagle, Colorado*

Dieticians and scientists can measure calories, or heat energy, on vastly different scales. Technically, a "calorie" (c or cal) is defined as the amount of heat required to raise the temperature of 1 gram of water 1° C. But the large calorie, also known as the kilogram calorie or kilocalorie (Cal or kcal), one thousand times greater than the scientific calorie, is the one used to measure food energy. Christopher Smith, of Kansas State University, cited in our article, says that adult male red squirrels need to consume 117 kcal per day, which equals just 117 total dietary calories, as most readers on reducing diets will be gratified to know.

*Natural History* regrets the failure to convert the number to common-sense usage. In fact, 117,000 calories would fill the daily food requirement of fully 1,000 red squirrels scampering through the maples or of a single, 500-pound red squirrel striking terror into the hearts of North Woods campers.—*Ed.*

## WHAT'S IN A NAME?

In his article on Maya agriculture ("Roots," February 1991), Don Rice enumerated several traditional food crops, including "yucca." This name has some confusion connected with it, which I would like to point out. The desert plants familiar to North Americans, genus *Yucca*, were not, so far as I know, cultivated by the ancient Maya (as the superficially similar *Agave* was). The crop known today in the Yucatán and Central America as "yucca" or "yuca" is the cassava, also mentioned in the list of crops. Cassava (genus *Manihot*) is a starchy root crop—one species is the source of tapioca. The plant is quite different from *Yucca*.

The origin of the name "yucca" is not known, but "yuca" is indigenous (Taíno). Neither is related to the root of "Yucatán," which apparently is a Spanish rendering of a Maya phrase meaning "What did he say?"

DAVID S. KYSER
*Ridgecrest, California*

## A STICKY BUSINESS

After a long search, our printer, Ringier America, of Jonesboro, Arkansas, has finally found an adhesive that performs two conflicting tasks. It holds the mailing label securely while the magazine passes through the perils of the U. S. Post Office, yet the label peels off cleanly when the subscriber wants to remove it.

We hope this wonder of adhesion technology will make everyone happy: our designer and the many readers who have complained about the defacing of our beautiful covers; and environmentalists everywhere who object to plastic wrappers and realize that the magazine can be recycled more easily without the address label and its adhesive. It should also help protect the privacy of the many civic-minded subscribers who recycle their *Natural Historys* to libraries and schools.

The new adhesive was used for mailing labels attached to this issue, so you may want to test it. If you have any problems, please tell us, as we know from experience you will.—*Ed.*

Birds of Cape St. Mary's

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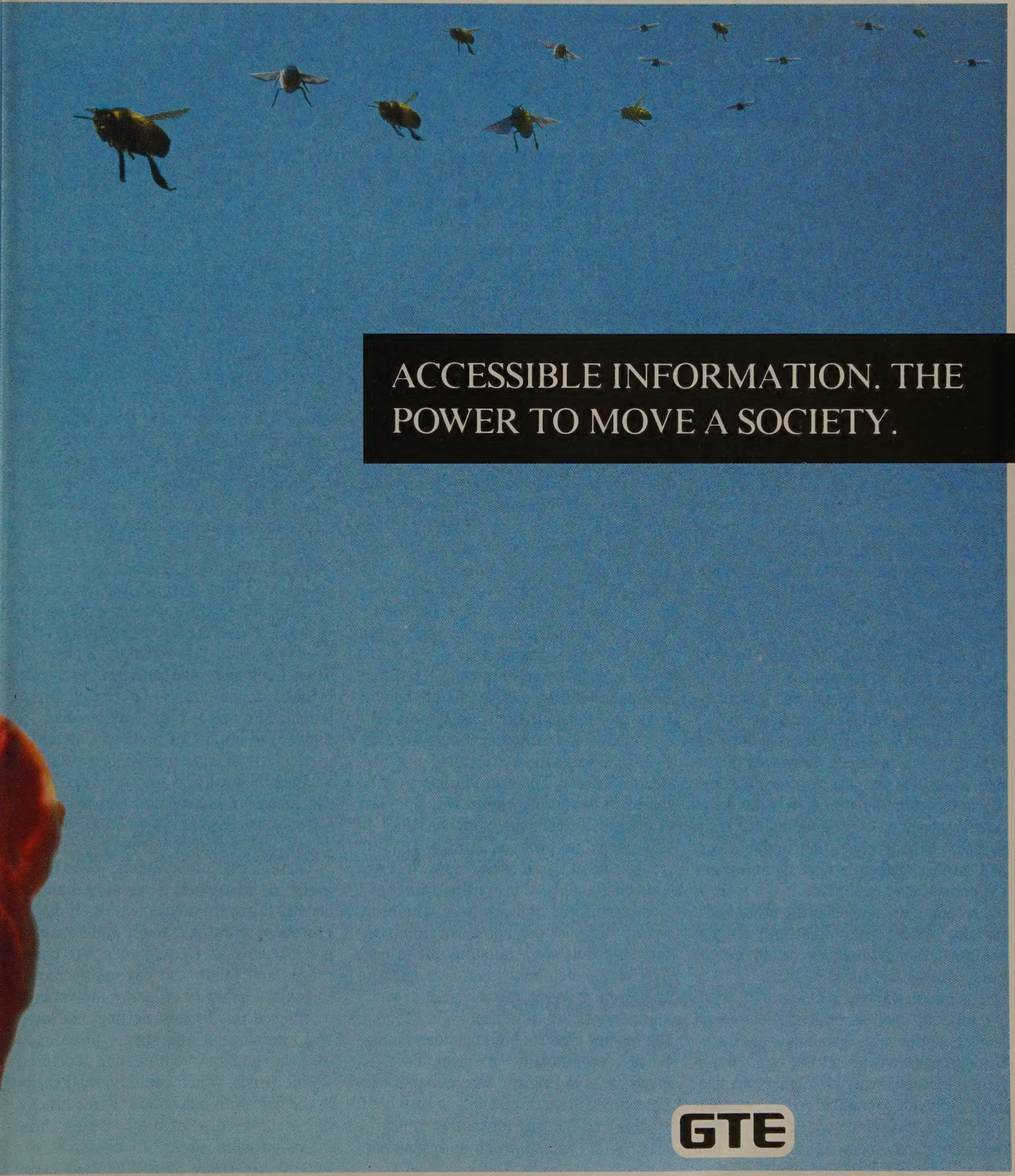


THE POWER IS ON

# A Well-traveled Warbler's Repertoire

*As it migrates from English hedgerows to Zambian acacia groves, the bird collects songs*

by Martin G. Kelsey

I am sitting in a steep, fallow field in the English midlands. At one o'clock on this morning in early June, only the distant rumble of traffic and the occasional bark of a fox ruffle the silence of the night. And then, just as I am sinking my hands even deeper into my coat pockets against the growing chill, a clear, urgent song comes from the tall vegetation of the valley bottom, spreading across the field like a beacon of sound. It is confusingly complex, incorporating faithful copies of the songs and calls of a host of birds. Here and there I recognize sounds that I have heard the day before: the chatter of sparrows, alarm calls of thrushes, snatches of skylark song, a swallow's twitter. But mixed in with these are sounds I recognize only later: songs that emanate not only from the familiar birds of the English hedgerows and meadows but also from those of the African savannas and bushlands—drongos, bee eaters, weaverbirds, and sunbirds.

The mimic responsible for this nocturnal medley is a small, brown bird, the marsh warbler. For just three or four days of the season, the marsh warbler sings nearly nonstop, day and night, from patches of lush vegetation beside rivers and ditches. This intensive singing spans the period between the return of a male to his breeding territory and the arrival of a female. After that, nighttime singing ceases, and song is then given only in short bursts during territorial combat.

The marsh warbler is a migrant, spending just two months or so on its central Eurasian breeding grounds—from the British Isles eastward to the Ural Mountains—before leaving in August on a five-month odyssey to tropical Africa, where it spends the remainder of the year before returning north in April. I wanted to find out how marsh warblers, along with an estimated five billion individuals of other northern migrant species, competed for their diet of insects with the many permanent insectivorous residents of Africa. So for three years I, too, became a migrant, matching my annual cycle with that of the warbler.

In 1984, I met the Belgian scientist Françoise Dowsett-Lemaire, who had studied marsh warblers ten years earlier. Particularly interested in song, she was the first person to describe the extent of the marsh warbler's ability to imitate other species. Using a sonograph, which provides a sort of sonic fingerprint for each burst of song, she painstakingly compared marsh warblers' songs with those of other birds to match up the imitation with the real thing and to double-check each apparent case of mimicry. She found that marsh warblers imitated more than 210 species, on average mimicking 76 different species during a thirty-minute bout of song. Dowsett-Lemaire suggested that if I was interested in studying marsh warblers in Africa, I should go to Zambia, in south-central Africa. There in the heart of the warbler's wintering range was an ideal study area: Lochinvar National Park.

I arrived in Africa in January 1985, to be welcomed by Geoffrey Howard of the University of Zambia. Within two days I was established at Lochinvar. The rainy season was just beginning, and the scattered thickets were bursting out in leaf. The coarse-stemmed grass was growing rapidly, and within a few weeks it would stand more than three feet high. Much of the habitat consisted of abandoned maize fields. Superficially, it resembled my study areas in England where marsh warblers breed in nettle and willow herb beds, singing and hunting for insects in nearby clumps of willow trees and hawthorn bushes.

Within minutes of setting out on my first walk at Lochinvar, I found a marsh warbler. Renewing the acquaintance of a species that I had known so intimately in Europe in such different circumstances was an extraordinary experience. As I watched, the bird moved from one grass stem to another, reaching out at full stretch to pick an insect from the underside of a leaf. Something then caught its attention, and it flew up into an acacia bush and flattened its body feathers, adopting an elongated stance. It peered into the center of the bush, then flew in, to reappear later chasing out another marsh warbler.

Shortly afterward, I heard the chattering of small birds that is often associated with mobbing behavior, their ganging up to harry a lone predator, as when North American blue jays scold and chase a hawk. Looking for the source of the alarm, I found a mamba snake resting on a branch. Frenzied birds surrounded it. Snakes are important predators of birds, particularly of eggs and helpless young. I scanned the bush and among several African species of birds found two species of European migrants: an icterine warbler and two more marsh warblers.

These casual observations, while interesting, could amount to no more than anecdotes in any rigorous scientific study. So I set about marking as many individuals as possible so that I could map out home ranges and follow the day-to-day movements and behavior of known individuals. I achieved this by mist netting, marking, and releasing all migrants. I fitted each bird with a unique combination of colored plastic bands, which could be read easily in the field with binoculars. Three times a day I surveyed a set route, taking three hours on each survey to crisscross my twenty-acre study area. I plotted every sighting of a marsh warbler on a large-

scale map and recorded its habitat and behavior.

I discovered as many northern migrant individuals as African residents among the small insectivorous birds, and the most common migrant of all was the marsh warbler. When the rainy season in southern Africa provides a bumper crop of food, the incoming migrants arrive to exploit it. Throughout the tropics, migrants from high latitudes tend to occupy habitats that vary climatically, and thus in food availability, from season to season. Perhaps they choose these areas because they contain fewer permanent local avian residents, which would find living in them difficult in the leaner, drier periods of the year. Very few migrants move into the lowland equatorial rain forests, which change little from one season to another and may sustain a larger population of resident African birds.

In Lochinvar National Park the marsh warblers arrive in late December, just as the grass layer is becoming lush. Their surprising abundance in my study area might be linked with their use of patches of long grass, as well as bushes, for foraging. Most of the other small insectivorous birds concentrated their activities in trees and bushes.

On their breeding grounds in the Northern Hemisphere, male marsh warblers are territorial only for the period prior to the arrival of the female and during her fertile period, which usually lasts less than ten days. The defended area itself is small, often no more than 120 square yards, although feeding areas are larger and usually overlap considerably. I found that when some marsh warblers reached Africa, they spent their entire sojourn within small patches, similar in area to breeding territories, although these overlapped with neighbors' areas. The chase between two marsh warblers that I had witnessed on my first day in Zambia was evidence of competition. I saw such chases quite often during the birds' arrival period when they were attempting to establish bases, but rarely saw them once the wintering population had stabilized. Other strands of evidence suggested that individuals maintained a level of territoriality even if competition for resources seemed slight at the time.

The relative abundance of northern migrants was not the only surprise in my study site. Song, too, was abundant. During survey walks in the Zambian bush, I would stop, shut my eyes, and imagine myself to be standing at the edge of a central European wood. Most of the song I heard came not from the African residents (many of which were now quietly in the midst of their breeding season) but from the migrants that I had come to study. Marsh warblers sang from the lower branches of bushes. Tiny willow warblers produced thin, delicate cadences from the tops of acacias, alongside icterine warblers with their nasal, ambling song. Garden warblers sang softly from thickets, and red-backed shrikes whispered raspingly from the same thorn bushes on which they had impaled their prey of small frogs. This winter singing fascinated me. Possibly it was simply a reflection of internal, hormonal changes that the birds were experiencing. Changes in testosterone levels can influence behavior enormously, and if gradual gonadal changes were taking place to prepare the birds for the breeding season (still several months and a long migratory journey away), then the onset of singing, I thought, might be an external expression of this.

I found that marsh warblers spent, on average, a seventh of the day singing but produced no song whatsoever at night. And although song output peaked just after dawn, it was usually delivered as short bursts during each hour of daylight. Individuals seemed to be uttering, at frequent intervals, a few song phrases during the course of their other, everyday activities, as if they were giving regular reminders to neighbors of their presence. Plotting the song positions on a map revealed something that was not obvious to me in the field. Individual feeding areas overlapped; the areas in which individual marsh warblers sang did not. The singers seemed to be declaring ownership of distinct core areas within their territory.

What was the purpose of maintaining such a stake? If food was as abundant as it appeared to be, why could not individuals roam freely? Why give up part of the day to singing in a territory? Possibly the birds were laying claim to resources for insurance purposes—not to satisfy immediate requirements, but to safeguard a supply for leaner times in the future. Studies of birds elsewhere have shown that some species will defend a resource even when food is plentiful and widespread. Barbara and David Snow described such behavior with mistle thrushes in England, which guard berry-laden bushes in the fall to insure fruit supplies in the depths of winter. That study provokes the fascinating thought that we have mistle thrushes to thank in England for the availability of yuletide holly berries.

In Zambia, marsh warblers start to sing when their annual molt begins. They molt rapidly, and for a time they cannot fly well. This means that they need to depend upon resources of a small patch to meet

Gertrud and Helmut Denzau

*On its European breeding grounds, a marsh warbler runs through its repertoire.*

the extra nutritional and energetic demands of molt. They, presumably, are reluctant to venture far for food, being particularly vulnerable to predation at the time. The rains end when most marsh warblers are still molting and before they have prepared for migration. A known, dependable source of food might be of crucial importance, and its maintenance might indeed justify the risk of a bird's advertising its presence to potential predators during the rigors of heavy molt.

In a stay of perhaps four months at its wintering site, a bird will learn many things crucial for survival—for example, the best and safest places to feed and to roost and the numbers and kinds of predators and competitors it is likely to encounter—that will stand it in good stead in the future. Time spent one year learning about local conditions can be used the next to secure and maintain ownership of the choice patches. Learning the ropes in a new site takes time and involves predation risks, and it may be why migrant birds of many kinds are remarkably faithful to certain breeding areas.

In my study population of marsh warblers, just under half returned the following winter to the same patch of thickets. The annual mortality rate of such birds is thought to be approximately 50 percent. If this is so, I was witnessing the return of almost the entire surviving population. In a feat of navigation, the warblers successfully rediscover, not just Zambia or Lochinvar National Park, but the very same clump of bushes they occupied a year earlier, after a journey of perhaps 4,800 miles.

This odyssey takes the marsh warbler from Europe, through the Middle East and the Arabian Peninsula, across the Red Sea to Sudan and into northeast Africa, the semiarid thorn-bush savannas of eastern Kenya, and then southward. Much of what we know of the migration route comes from conventional techniques of migration study: banding and observation. In Kenya, for example, some 30,000 marsh warblers have been trapped, banded, and released during their nocturnal, long-distance migration when attracted to the powerful game-viewing lamps at the Ngulia Safari Lodge in Tsavo West National Park. Indeed, we probably know more about the migration patterns of this species than those of many of the 200 or so species that migrate from Eurasia into Africa. However, parts of the journey remain mysteries. For example, what happens to marsh warblers for the six to eight weeks between their arrival in Sudan in August and their subsequent reappearance in Kenya in late October? We do not know if the birds stop migrating altogether and occupy resting areas or continue migrating but at a very slow pace. The latter possibility has been suggested by experiments at the Max Planck Institute in Germany to record internal annual migratory rhythms in marsh warblers. Searches in Ethiopia have failed to turn up more than a few individuals.

There is, however, one additional source of information. During the first months of its life, the marsh warbler learns the songs and calls of birds not just from its birthplace and wintering area but also from its migration route. This learning equips the marsh warbler with a ready-made, elaborate song with which to attract a mate and defend a territory. It also gives us an audio-travelogue. When Françoise Dowsett-Lemaire investigated the repertoires of twenty marsh warblers, she found that almost all imitated some species of very localized distribution in northeast Africa. The material exists for a dedicated ornitho-detective, armed with knowledge of the songs and calls of suitable indicator species from Europe and Africa, to decipher the marsh warbler's song and to unravel further the migratory story of this species. In the valleys of central Europe, for a few nights every spring, the marsh warbler sings its secret.

*Martin G. Kelsey studied marsh warblers while at the Edward Grey Institute of Field Ornithology at Oxford University. He is currently Programme Officer for the Americas at the International Council for Bird Preservation, based in Cambridge, England.*

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# What the Immaculate Pigeon Teaches the Burdened Mind

*To support his theory, Darwin studied the rock dove and its descendants*

by Stephen Jay Gould

Two successive symbols of Saint Louis typify the passages of our century. Saarinen's magnificent arch, gleaming and immaculate, seems to soar from the Mississippi River into heaven (an optical illusion, in large part, cleverly produced by a gradual decrease in edge length from fifty-four feet at the base of the structure to seventeen feet at the summit. Our minds work on the expectation of a constant size, and the marked decrease therefore makes the summit seem ever so much higher than its actual 630 feet—the size of an ordinary skyscraper in a modern city). By contrast, Saint Louis's older symbol, an equestrian statue of the eponymous Louis IX, the only canonized king of France, still stands in front of the Art Museum in Forest Park. It is anything but immaculate, thanks to that primary spotting agent of all cities—pigeons.

As a team, pigeons and the statue of Saint Louis go way back. The current statue is a 1906 recasting in bronze of the impermanent original made for the main entrance to one of the world's greatest expositions—the 1904 World's Fair, held to celebrate (if just a bit late) the centenary of the Louisiana Purchase. The Fair must have been spectacular; my wife's family, raised in Saint Louis, still mentions it with awe in stories passed down through three generations. The Fair gave us iced tea, ice cream cones, and a great song, "Meet Me in Saint Louis, Louis" (many folks don't even know the next line, "Meet me at the Fair").

A Ferris wheel stood twenty-five stories high; Scott Joplin played his rags. The Pike, main street of the amusement area, featured daily reenactments of the Boer War and the Galveston Flood. The world's greatest athletes came to participate in the third Olympic Games. The fairgrounds, bathed at night in the newfangled invention of electric lighting, inspired Henry Adams to write:

> The world has never witnessed so marvelous a phantasm; by night Arabia's crimson sands had never returned a glow half so astonishing [a statement that will need revision after the night bombing of our Desert Storm], as one wandered among long lines of white palaces, exquisitely lighted by thousands and thousands of electric candles, soft, rich, shadowy, palpable in their sensuous depths [from *The Education of Henry Adams*].

This statement also makes sense of the next two lines of the famous song: "Don't tell me the lights are shining / Any place but there."

Intellectuals must be constantly clever and industrious. We know that we are peripheral to society's main thrust, and we must be constantly vigilant in seeking opportunities to piggyback on larger enterprises—to find something so big and so expensive that prevailing powers will grant us a bit of space and attention at the edges. The hoopla and funding of major exhibitions often give us a little room for a smaller celebration in our own style. I was invited to give a speech at something called the Academic Olympiad in Seoul during the last great athletic show. (I wasn't able to go and never heard boo about the outcome—although television deluged us with all the details about javelins and the hop, step, and jump.) Similarly, as the 1904 World's Fair led to the establishment of Washington University, academicians rallied to hold a Congress of Arts and Science at the Universal Exposition (as the Fair was officially called). At this convocation, the great American biologist Charles Otis Whitman gave a leading address with the general title: "The Problem of the Origin of Species." He spoke primarily about pigeons.

Whitman's work, while treating so humble a subject, had a certain panache and boldness. He wrote at a time when biologists, although fully confident about the fact of evolution, had become very confused and polemical about the causes of evolutionary change. Darwin's own theory of natural selection had never commanded majority support (and would not emerge as a consensus until the 1930s). As visitors ate their first ice cream cones on the Pike, at least three other theories of evolutionary change enjoyed strong support among biologists: (1) the inheritance of acquired characters, or "Lamarckism"; (2) the origin of species in sudden jumps of genetic change, or "mutationism"; (3) the unfolding of evolution along limited pathways set by the genetic and developmental programs of organisms, or "orthogenesis" (literally, "straight line generation"). Whitman, who had been raising and breeding pigeons for decades, defended the last alternative, orthogenesis, and thereby relegated Darwinian natural selection to a small and subsidiary role in evolution.

Whitman's boldness did not lie in his choice of the orthogenetic theory, for this argument was a strong contender in his day, although probably the least popular of the three major alternatives to Darwinism. We judge a man intrepid when he uses his adversary's tools or data to support a rival system. A famous story about Ty Cobb tells of his disgust with Babe

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Ruth's new style of power hitting (Ruth swatted more home runs per year all by himself than most teams had managed in a season during earlier times). Cobb, the greatest and most artful practitioner of the earlier style of slap, hit, and scramble for a run at a time, held his hands apart on the bat, slipped them together high on the bat as the pitch came in (thus achieving maximal control while sacrificing power), and then slapped the ball to his chosen spot. Ruth, by contrast (and following the strategy of all sluggers), held the bat at the end and swung away, missing far more often than he connected. Cobb regarded this style as easy and vulgar, however effective. One day near the end of his career, and to show his contempt in the most public way, Cobb ostentatiously held the bat in Ruth's manner, hit three home runs in a single game, and then went right back to his older, favored style forever after.

Whitman's assault on Darwin's theory from within was far bolder and more sustained, if not quite so showy. For Whitman had chosen, for study over decades, the very organisms—pigeons—that Darwin had selected as the primary empirical support for his own theory.

Darwin stated in chapter one of the *Origin of Species:*

> Believing that it is always best to study some special group, I have, after deliberation, taken up domestic pigeons. I have kept every breed which I could purchase, or obtain, and have been most kindly favored with skins from several quarters of the world.... I have associated with several eminent fanciers, and have been permitted to join two of the London Pigeon Clubs.

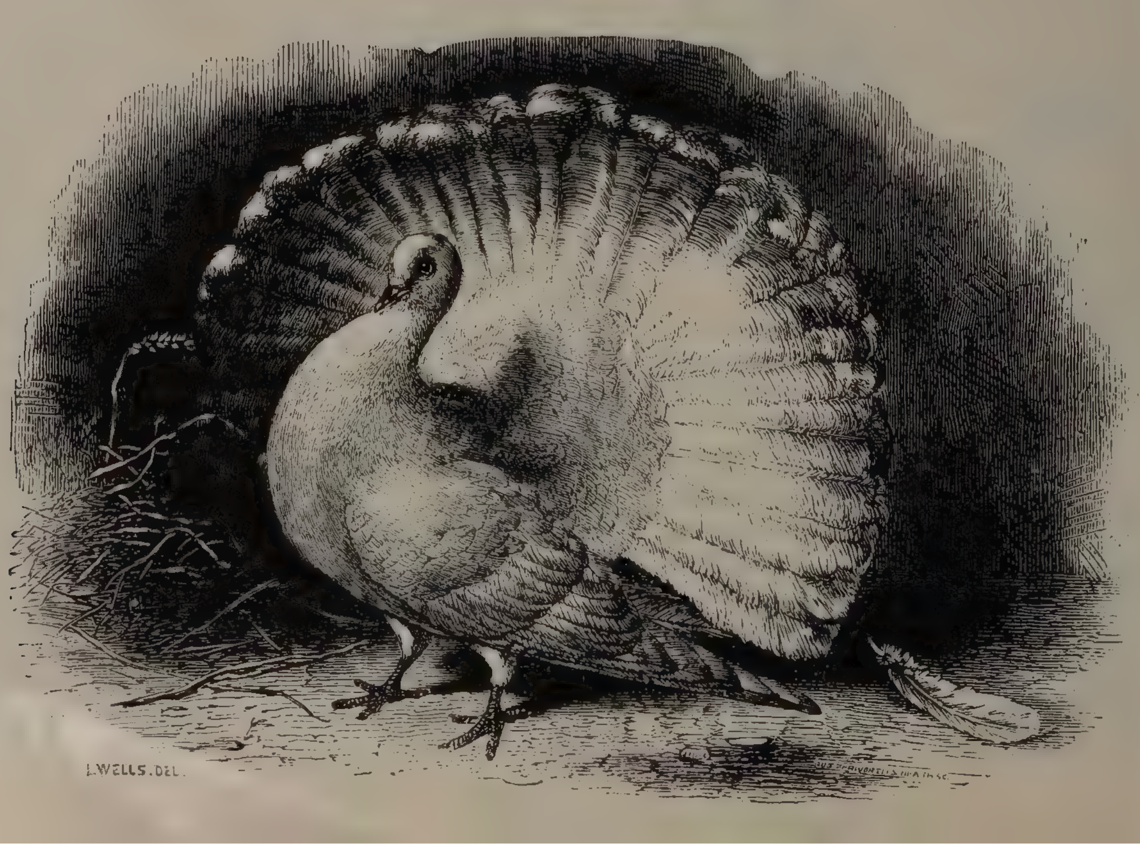
Darwin stated an excellent reason for his choice in the next sentence:

> The diversity of the breeds is something astonishing. Compare the English carrier and the short-faced tumbler, and see the wonderful difference in their beaks.... The common tumbler has the singular and strictly inherited habit of flying at a great height in a compact flock, and tumbling in the air head over heels.... The Jacobin has the feathers so much reversed along the back of the neck that they form a hood.... The fantail has thirty or even forty tail-feathers, instead of twelve or fourteen, the normal number in all members of the great pigeon family; and these feathers are kept expanded, and are carried so erect that in good birds the head and tail touch.

These breeds are so different that any specialist, if "he were told that they were wild birds," would assume major taxonomic distinctions based upon substantial differences. "I do not believe," Darwin wrote, "that any ornithologist would place the English carrier, the short-faced tumbler, the runt, the barb, pouter, and fantail in the same genus."

And yet, demonstrably by their interbreeding and their known history, all these pigeons belong to the same species and therefore have a common evolutionary source—the rock pigeon, *Columba livia.* Darwin wrote: "Great as the differences are between the breeds of pigeons, I am fully convinced that the common opinion of naturalists is correct, namely, that all have descended from the rock-pigeon (*Columba livia*)." (Darwin might have chosen the even more familiar example of dogs to make the same point, but he was not convinced that all dog breeds came from a common wolf source, whereas the evidence for a single progenitor of all pigeons seemed incontrovertible.) Only one step—the key analogical argument that powers the entire *Origin of Species*—remained to secure the most important argument in the history of biology and to make pigeons the heroes of reform: if human breeding of pigeons could produce, in a few thousand years at most, differences apparently as great as those separating genera, then why deny to a vastly more potent nature, working over millions of years, the power to construct the entire history of life by evolution? Why acknowledge the plain fact of evolution among pigeons and then insist that all natural species, many no more different one from the other than pigeon breeds, were created by God in their permanent form?

Whitman, of course, did not disagree with Darwin's focal contention that pigeons had evolved, but he strongly questioned Darwin's opinion on *how* they and other species had arisen. Charles Otis Whitman (1842–1910), although scarcely a household name today, was the leading American biologist of his generation. He was, perhaps, the last great thinker to span the transition from the pre-Darwinian world to the rise of twentieth-century experimental traditions—for he had studied with Louis Agassiz, the last true creationist of real stature, and he lived to found and direct the symbol of modernism in American biology, the Marine Biological Laboratory at Woods Hole. In his research, Whitman was best known for meticulous work on "cell lineage" studies in embryology—tracing the eventual fate of the first few embryonic cells in forming various parts of the body. In promoting this form of research as canonical in Woods Hole, and in establishing at his new laboratory the finest young American biologists, Whitman succeeded in bringing to this country the experimental and mechanistic traditions championed as the soul of "modernism" in Europe.




*Darwin included this illustration of the "showiest" pigeon breed, the English fantail, in his book* The Variation of Animals and Plants under Domestication.
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In this light, I have always had trouble remembering that Whitman's main love in research lay in the opposite camp of "old-fashioned" and largely descriptive natural history—decades of work on the raising, breeding, and observation of pigeons. This passion even led to his death. In Chicago (where he served as professor of biology at the university), on the first chill day of December 1910, Whitman worked all afternoon in his backyard, hastily preparing winter quarters for his pigeons to save them from the cold. As a result, he developed pneumonia and died five days later. F. R. Lillie, once his assistant and then his successor at Woods Hole, eulogized his old boss: "In his zeal for his pigeons, he forgot himself."

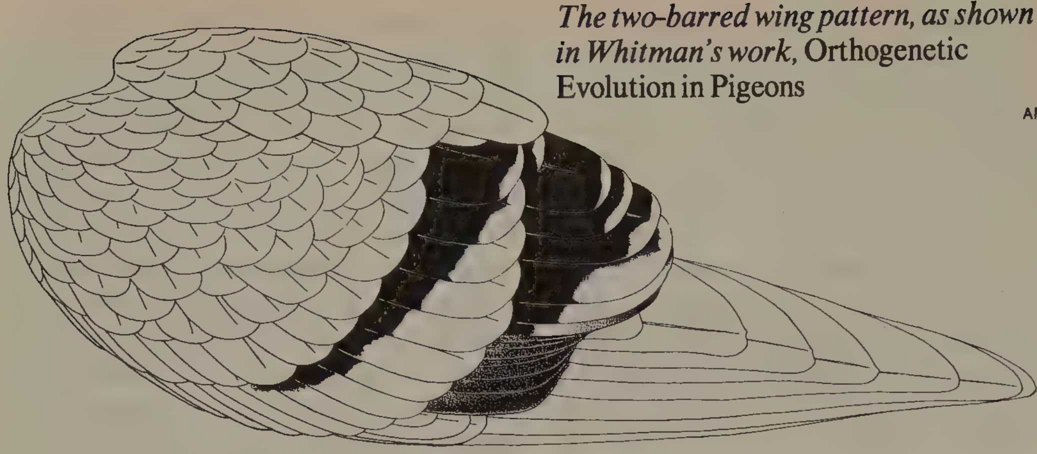
Unfortunately, Whitman died before completing and integrating his lifelong work on pigeons. He had published a few preliminary addresses (most notably, his offering in Saint Louis), but never the promised major statement. I can't help thinking that the history of evolutionary thought might have been different had Whitman lived to promulgate and proselytize his non-Darwinian evolutionary ideas. His colleagues did gather his notes and data into a three-volume posthumous work on pigeons, which finally appeared in 1919. But this work (the basis of my essay) was too disjointed, too incomplete, and above all, too late to win its potential influence.

Darwin's pigeon agenda had been wider than the simple demonstration of evolution. He also wished to promote his own theory about how evolution had occurred—natural selection. Again, he relied on argument by analogy: pigeon breeds had been made by artificial selection based on human preferences for gaudiness (pouters, fantails) or utility (carriers, racers).

> When a bird presenting some conspicuous variation has been preserved, and its offspring have been selected, carefully matched, and again propagated, and so onwards during successive generations, the principle is so obvious that nothing more need be said about it. [This quotation comes from Darwin's most extensive discussion of pigeons, two long chapters in his 1868 book, *The Variation of Animals and Plants under Domestication.* Other statements are cited from the *Origin of Species,* 1859.] May not those naturalists who . . . admit that many of our domestic races have descended from the same parents—may they not learn a lesson of caution, when they deride the idea of species in a state of nature being lineal descendants of other species?

Orthogeneticists like Whitman did not deny natural selection but viewed Darwin's force as too weak to accomplish anything but a bit of superficial tinkering. Natural selection, they argued, can make nothing, and can only accept or reject the variation that arises naturally among differing organisms in an interbreeding population. If the genetic and embryological systems of organisms prescribe a definite direction to this variability, then natural selection is rendered powerless to set the course of evolutionary change. Suppose, for example, that size in offspring only varied in a single direction from parental dimensions; that is, all kids ended up either the same size or taller than their folks. What could natural selection do? Darwin's force could hasten an inherent trend by favoring the taller offspring. At most, selection could prevent a trend, and keep the population stable, by eliminating the taller offspring and preserving only those of parental dimensions. But selection could not work counter to the inherent direction of variation because no raw material would be available for trends in any direction other than increasing size. Thus, selection would be a force subsidiary to the internal tendency for directional variation, or orthogenesis.

Darwin, of course, was aware of the logic of this destructive argument. He



*The two-barred wing pattern, as shown in Whitman's work,* Orthogenetic Evolution in Pigeons

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countered by claiming that variation has no inherent direction and occurs "at random" relative to the favored path of natural selection. (This is the context for Darwin's confusing claim that variation is random—a statement that has led many people into the worst vernacular misconception about Darwinism: the false belief that Darwin viewed evolutionary change itself as random, and that the manifest order of life therefore disproves his theory. In Darwin's scheme, variation is random, but natural selection is a deterministic force, adapting organisms to changes in their local environments. In fact, Darwin made his claim about the randomness of variation in order to empower natural selection as a directional agent.) If variation is only random raw material, occurring in no favored direction relative to environmental advantages, then some other force must shape this formless potential into adaptive change. Random raw material needs another force to carve out and preserve the advantageous portion—and natural selection plays this role in Darwin's system. But orthogenetically directed variation requires no other shaping force and can set an evolutionary trend all by itself.

Whitman therefore set out to prove that an inherent trend in variation pervades the pigeon lineage—a trend too powerful for natural selection to alter in direction or even to slow substantially. Whitman based his argument on the bird's patterns of coloration.

The feral pigeons that speckle our public statuary show two basic color patterns in their extensive repertoire of variation. Some have two black bars on the front edges of their wings and a uniform gray color elsewhere; others develop black splotches, called checkers, on some or all wing feathers, but also retain the two bars (although usually in more indistinct form). The bars, in any case, are composed of checkers (on several adjacent feathers) that line up to produce the impression of a broad, continuous stripe.

Darwin had assumed that ancestral pigeons were two-barred and that checkers represented an evolved modification by intensification of coloration. Whitman reversed Darwin's perspective:

> The latter [two-barred] was regarded by Darwin as the typical wing pattern for *Columba livia*; the former [checkered] was supposed to be a variation arising therefrom, a frequent occurrence but of no importance. Just the contrary is true; the checkered pigeon represents the more ancient type, from which the two-barred type has been derived.

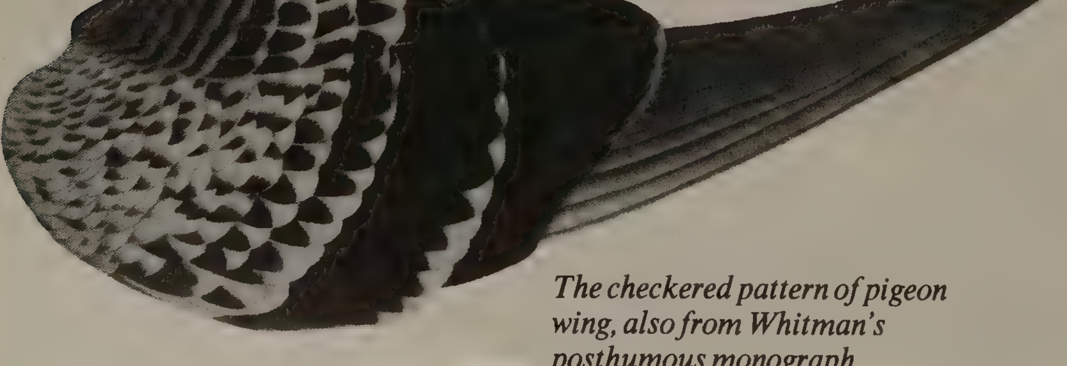
This reversal is of no great significance in itself, unless you happen to be a pigeon fancier devoted to the peculiarities of these generally unloved creatures. But Whitman made much of his inversion because his favored sequence of checkers-to-bars formed the major part of his proposed (and inexorable) orthogenetic sequence of internally prescribed variation—an evolutionary pattern inherent in the biological organization of pigeons and quite beyond the power of natural selection to deflect. The orthogenetic trend, Whitman argued, moved from original diffusion to later concentration of color. Checkers plus indistinct bars must come before clear bars and no checkers. In the lines following the quotation just cited, Whitman wrote:

> The direction of evolution in pattern in the rock pigeons has been from a condition of relative uniformity to one of regional differentiation.

But Whitman had an even bolder vision, based on the same orthogenetic pattern. Checkers-to-bars was no circumscribed peculiarity of domestic pigeons but only part of a much more extensive orthogenetic trend that pervaded the entire pigeon family (including all other species from mourning dove to passenger pigeon, which became extinct in the decade between Whitman's death and the posthumous publication of his monograph), and perhaps even all coloration in birds—an inherent and ineluctable progression from an original homogeneous checkering on all feathers, to the concentration of color in certain areas (checkers plus bars, and then to bars alone), to the reduction and weakening of these concentrations, to the final elimination of all color. Whitman located the ancestral state in the uniform checkering of some species—the "turtle dove pattern" in his terminology—and the final goal in some idealized, albinized version of the Holy Ghost, depicted as a pure white dove in so many medieval paintings. In short, and in his words, from uniform spotting to "immaculate monochrome," a most unpigeonlike state (in both appearance and deed), at least in our metaphors (also the quotation that piqued my interest, inspired this essay, and cast my initial thoughts toward Saint Louis). In a remarkable vision of inexorable movement through the entire great family of pigeons, Whitman wrote:

> When we look around among allied species and see the same bars reduced to about half dimensions in the rock pigeon of Manchuria, reduced to mere remnants of two to six spots in the stock dove, carried to complete obsoletion [*sic*] or to a few shadowy reminiscences in . . . *Columba rufina* of Brasil, gone past return in some of our domestic breeds and in many of the wild [doves and pigeons]—when we see all these stages multiplied and varied through some 400 to 500 wild species and 100 to 200 domestic breeds, and in general tending to the same goal, we begin to realize that they are . . . slowly passing phases in the progress of an orthogenetic process of evolution, which seems to have no fixed goal this side of an immaculate monochrome—possibly none short of complete albinism.

Moreover, while the progress of the



*The checkered pattern of pigeon wing, also from Whitman's posthumous monograph*

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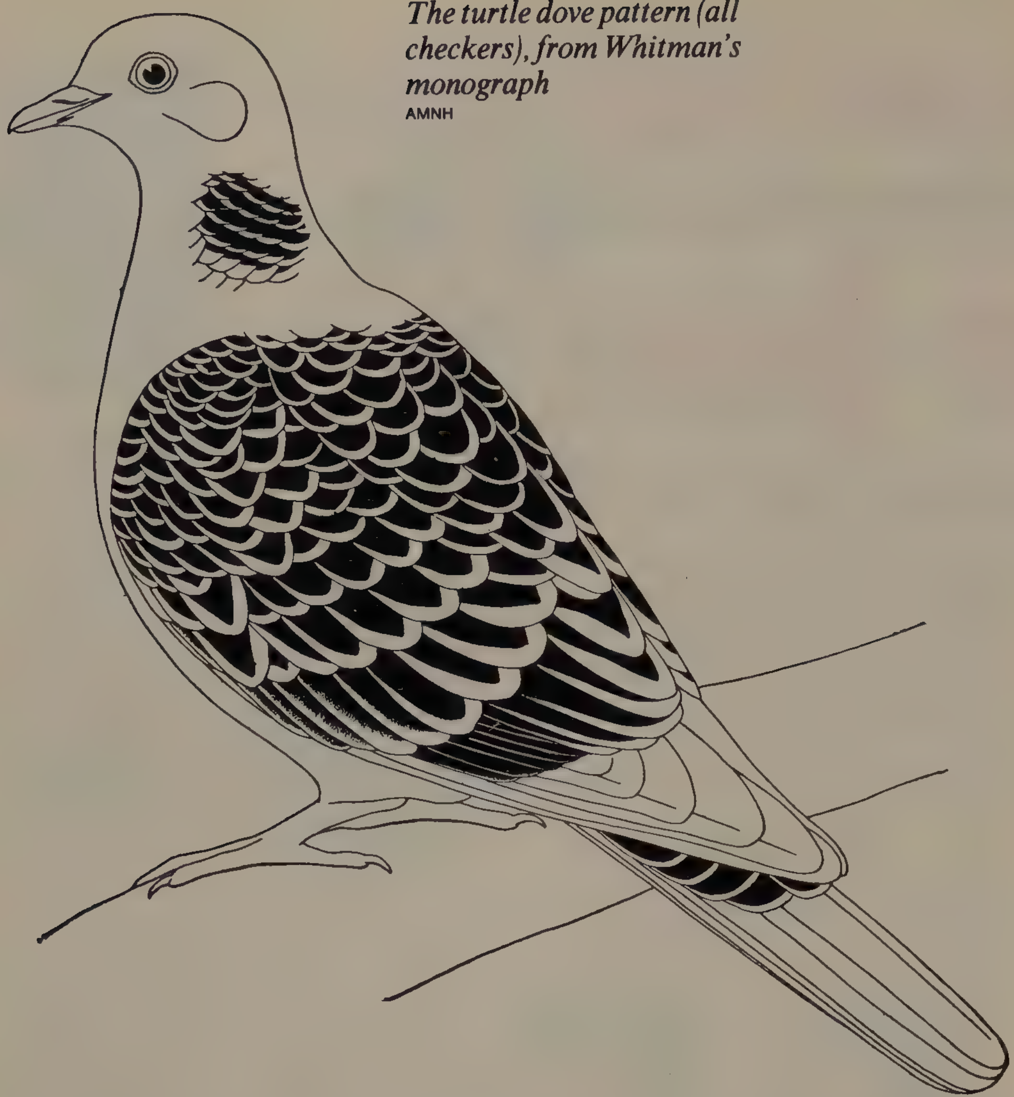

*The turtle dove pattern (all checkers), from Whitman's monograph*
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trend may be "lengthened or shortened, strengthened or weakened" by such subsidiary forces as natural selection, the orthogenetic sequence is invariable:

> The steps are seriated in a causal, genetic order—an order that admits no transpositions, no reversals, no mutational skips, no unpredictable chance intrusions.

When we discern the proper sequence of orthogenetic stages, evolution may become a predictive science: "Not only is the direction of the change hitherto discoverable, but its future course is predictable."

I have not resurrected Whitman's largely forgotten work in order to defend orthogenesis as a replacement for natural selection, for this is truly a dead issue decided long ago in Darwin's favor. Rather, from my deep admiration of Whitman's keen intelligence and my abiding respect for his decades of careful work with pigeons, I do wish to point out that his conclusions were not foolish and that several aspects of his work would repay our close study, even today. Consider three points that might prompt sympathy and interest.

1. *The false charge of teleology.* The standard one-liners of evolution texts dismiss orthogenesis as a theistically inspired, last-gasp effort to salvage some form of inherent goal and purpose in a Darwin's new world. In this canard, supporters of orthogenesis abandoned rationality itself to embrace for their explanation of life a woolly mysticism of "vital forces" and "inherent directions"—the very concepts that science had struggled to discard in field after field, from cosmology to physics to chemistry. Whitman has been viewed as a particularly sad example of this slippage and surrender, for he had been such a committed mechanist in his earlier embryological work.

This hurtful charge is not only wrong but entirely backward. Whitman and nearly all other prominent supporters of orthogenesis maintained as firm a commitment to mechanical causation (some today might argue too firm), and as strong an aversion to mystical or spiritual direction, as any contemporary in this late nineteenth century age of industrial order. In the opening paragraph of his 1919 monograph on pigeons, Whitman wrote:

> His [Darwin's] triumph has won for us a common height from which we see the whole world of living beings as well as all inorganic nature; phenomena of every order we now regard as expressions of natural causes. The supernatural has no longer a standing in science; it has vanished like a dream, and the halls consecrated to its thralldom of the intellect are becoming radiant with a more cheerful faith.

In fact, Whitman's orthogenesis arose from his mechanical perspective, not in opposition to his former life's work. The orthogenetic trend was not a mystical impulse from outside but a mechanistic drive from within, based upon admittedly unknown laws of genetics and embryology. His work on cell lineages had mapped the fate of earliest cells in the embryo and had indicated that the source of eventual organs could be specified even in the tiny and formless clump of initial cells. If embryos grew so predictably, why should evolutionary change be devoid of similar order? "I venture to assert," Whitman wrote,

> that variation is sometimes orderly and at other times rather disorderly, and that the one is just as free from teleology as the other. . . . If a designer sets limits to variation in order to reach a definite end, the direction of events is teleological; but if organization and the laws of development exclude some lines of variation and favor others, there is certainly nothing supernatural in this.

2. *Whitman's evidence.* Modern detractors who misconstrue orthogenesis as old-fashioned teleology often assume that its supporters could only have been working on hope and the flimsiest of supposed evidence. But Whitman spent decades gathering reams of fascinating data (not all properly interpreted in our view, but still full of interest). He marshaled three major sources of evidence to support his orthogenetic theory: breeding, comparative anatomy, and ontogeny (the growth of individual birds).

In breeding, he found that he could develop a two-barred race from checkered parents by selecting birds with the weakest checkers in each generation. But he could never produce checkered birds from two-barred progenitors. In comparative anatomy, he argued that species judged more ancestral on other criteria grew plumages of early stages in the orthogenetic series. In ontogeny, he found that juvenile plumage exhibited earlier stages than adult feathers (a juvenile bird might molt its checkered feathers and then grow a two-barred adult plumage). Most nineteenth-century biologists believed that "ontogeny recapitulates phylogeny"—a mouthful meaning that individuals, in their embryology and growth, tend to pass through stages representing adult forms of their ancestry. Juvenile plumage would therefore represent an ancestral condition. The law of recapitulation is wrong (see my book *Ontogeny and Phylogeny*), but you can't blame Whitman for accepting the consensus of his time.

3. *Channels versus one-way streets.*

Whitman viewed his series of orthogenetic stages as a forced pathway—a one-way street with pigeons as the cars. He was clearly wrong in this, and two major errors invalidate his form of orthogenesis. First, the cars can go in either direction: Whitman's series may carve a road into a complex landscape, but the traffic flows both ways. Pigeons can either gain or lose color. Second, I doubt that either the checkered or two-barred condition represents a primitive state for domestic pigeons. The ancestor of domestic races was a population, not an individual, and populations are variable. I suspect that the parental population included both checkered and two-barred birds within a spectrum of variation and that the spectrum represents the ancestral condition.

But think about Whitman's vision in a slightly modified form and we have an idea that is not only valid but also full of potential insight in correcting a major misconception and teaching a fundamental truth about evolution. Think of this one-way street as a channel instead—a favored pathway of evolutionary variation set by the inherited genetic and developmental programs of organisms.

Evolution does not move in predictable and preformed directions; organisms are not balls on the top of inclined planes. The inherited constitution of organisms surely sets limits of all kinds upon possibilities for variation and just as surely channels change along certain pathways.

If natural selection controlled evolution entirely, then no such limits and pathways would exist, and organisms would be like billiard balls, fully capable of moving in any direction and subject to any change in position induced by the pool cue of natural selection. But, to borrow an old metaphor from Darwin's brilliant cousin Francis Galton, suppose that organisms are polyhedrons rather than billiard balls, and that they can only move by flipping from one side (on which they now rest) to an adjacent facet. They may need a push from natural selection to move at all, but the direction of change is largely set by internal limitations and possibilities. If inherited genetic and developmental programs build the facets of Galton's polyhedron, then strong internal constraints upon evolutionary change must exist, and Whitman's insight is correct, so long as we convert his one-way streets into channels—that is, strong biases in the direction of variation available for evolutionary change. Moreover, Whitman probably identified the most important internal channel of all—the pathway of ontogeny, or the growth of individuals. Evolutionary change works most easily with a direction

already established in growth—lengthening a bit here, cutting out a stage or two there, changing the relative timing of development among organs and parts.

The greatest vernacular misconception of evolution views the process as an inexorable machine, working to produce optimal adaptations as best solutions to problems posed by local environments and unconstrained by the whims and past histories of organisms. For example, I have monitored the "Ask the *Boston Globe*" science query column for years and have never known it to answer an evolutionary question in any but an adaptationist way. One correspondent asked, "Why do we have two breasts?" and the paper answered by citing a theory that the "right" number of breasts (for optimal adaptation) is one more than the usual number of offspring, thus providing a margin of safety, but not so large a margin as to become a burden. Since human females almost always have but a single child, two is the right number of breasts by this argument rooted in natural selection. I couldn't help but laugh when I read this conclusion. I do grasp the logic, but surely the primary channel of our anatomical design—bilateral symmetry—has something to do with the solution. Most externalities come in twos on our bodies—eyes, nostrils, ears, arms, legs, and so on—and the reason cannot be singleton births. Isn't this prior channel of architecture more likely to be the primary reason for two breasts?

If the adaptationist vision were true, we might gain the comfort of seeing ourselves, and all other creatures, as quintessentially "right," at least for our local environments of natural selection. But evolution is the science of history and its influence. We come to our local environments with the baggage of eons; we are not machines newly constructed for our current realities. These historical baggages are expressed as the genetic and developmental channels that led Whitman too far, but that, properly interpreted as strong biases in variation rather than one-way streets of change, would give us a much richer view of evolution as a subtle balance between constraints of history and reshapings by natural selection.

The power of the channels is a key to understanding our bodies and our minds; we will never grasp the evolutionary contribution to our nature if we persist in the naïve view that natural selection builds best solutions. We can accept the idea more readily for our bodies; hernias and lower back pain are the price we pay for walking upright with bodies evolved for quadrupedal life and not optimally redesigned. But how much of the quirkiness and limitations of our modes of thinking might also record a structure evolved during eons for other uses and only recently developing the varied phenomena of higher consciousness, and its primary tool of expression in language? Why are we so bad at so many mental operations? Why do we seem so singularly unable to grasp probability? Why do we classify by the painfully inadequate technique of dichotomy? Why can we not even conceive of infinity and eternity? Is the limit of current cosmological thinking a defect of data or a property of mind that gives us no access to more fruitful kinds of answers?

I do not mean this list as a statement of despair about our mental midgetry. To recognize a potential limit is to think about tools of possible transcendence. Freedom, as Spinoza said, is the recognition of necessity. Let us return once again to the proper metaphor of channels and remember the finest statement in literature about emerging from ruts: "There is a tide in the affairs of men, which, taken at the flood, leads on to fortune."

*Stephen Jay Gould teaches biology, geology, and the history of science at Harvard University.*

# Death and Taxes

*Every empire has its price*

by Samuel M. Wilson

"Taxation is made more shameful and burdensome," wrote Salvian the Presbyter in the fifth century, "because all do not bear the burden of all. They extort tribute from the poor man for the taxes of the rich, and the weaker carry the load for the stronger" (*The Writings of Salvian the Presbyter,* Catholic University Press, 1947). Salvian was complaining of the tax burden imposed on conquered territory by the Roman Empire, but the same sentiments might have been expressed by New World peoples as they were incorporated into the expanding Spanish empire. In a large part of the New World, most notably in regions ruled by the Aztec and Inca empires, people probably grumbled about taxes long before the arrival of the Europeans. From the smallest agrarian chiefdom to empires spanning continents, governments throughout history have lived off the surplus produced by the populace, and they have engineered economies to insure that such a surplus was produced.

When they conquered the most complex societies of the New World, the Spaniards substituted their own systems of taxation for those already in place. How, we may wonder, did the conquistadors come to the conclusion that New World people owed them anything? Montezuma might have pondered this as he sat under house arrest in the Spaniards' quarters in Tenochtitlán. For most early Spanish conquerors, however, it was a given. Columbus took it for granted and had a tribute system in place on Hispaniola by 1494:

> All the natives between the ages of fourteen and seventy years bound themselves to pay him tribute in the products of the country at so much per head, promising to fulfill their engagement. Some of the conditions of this agreement were as follows: the mountaineers of Cibao were to bring to the town every three months a specified measure filled with gold. They reckon by the moon and call the months moons. The islanders who cultivated the lands which spontaneously produced spices and cotton, were pledged to pay a fixed sum per head [*De Orbe Novo,* by Peter Martyr D'Anghera. Burt Franklin, 1912].

Perhaps for sixteenth-century Europeans (as in twentieth-century conventional wisdom) taxes were one of the two inescapable things. Or perhaps Spain, in demanding tribute from conquered peoples, took Rome as its model. Gaul and Britain and Spain itself—or the peoples and lands that then constituted Spain—had paid tribute to Rome a thousand years before Columbus sailed.

Within the Roman system, as in almost all tax systems, the state's objective was to extract the greatest amount of money, goods, and services for the least cost. During the period of the Roman Republic, the imposition of tribute on conquered territories was an important motivation for the conquests in the first place. Nevertheless,

*Spaniards under Balboa (center) quarrel over the gold objects bestowed on them by Panciaco, the chief who showed them the way to the Pacific Ocean. In the background of this late sixteenth century illustration by Flemish engraver Theodore de Bry, the Europeans reward Panciaco with baptism.*

From *Discovering the New World,* by Michael Alexander


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to subjugate the provinces completely and hold them to the letter of tribute demands was probably impossible and certainly not expedient. Conquered territories attempted to minimize their tribute burden without attracting the attention of the imperial army. The Romans, too, were eager to preserve the peace.

For example, Julius Caesar's strategy for extracting tribute from the province of Gaul depended on convincing local leaders that producing tax revenues was in their interest. In Caesar's words (written in the third person):

> During the winter which he spent in Belgic Gaul Caesar made it his single aim to keep the tribes loyal, and to see that none had any pretext for revolt or any hope of profiting by it. The last thing he wanted was to have to fight a campaign immediately before his departure; for it would mean leaving Gaul in a state of rebellion when the time came to withdraw his army, and all the tribes would be only too willing to take up arms when they could do so without immediate risk. So he made their condition of subjection more tolerable by addressing the tribal governments in complimentary terms, refraining from the imposition of any fresh [tax] burdens, and bestowing rich presents upon the principal citizens. By these means it was easy to induce a people exhausted by so many defeats to live at peace [*The Conquest of Gaul,* Penguin Books, Ltd., 1951].

Spanish tacticians also knew that much was to be gained by co-opting the local rulers. They coerced and courted them into becoming agents of the empire who would collect tribute and keep the peace. Spain's treatment of its New World territories was similar in other respects to Rome's relationship to its provinces. To generate income, Spain placed the greatest effort in areas of greatest return (like the gold- and silver-mining regions), just as Rome exploited Britain's mineral wealth. Spain pensioned off its soldiers with grants of New World lands and the labor of conquered people, just as Rome granted parcels of conquered land to retiring soldiers to repay them cheaply and to further subdue the provinces. And like Rome, Spain kept the cost of having an army within bounds by using the threat of force more often than force itself.

As did Rome and Spain, the Inca empire in the Andes undertook its conquests with the smallest standing army possible. But their might was still adequate to subjugate unwilling populations whose traditional leadership had nothing to gain and everything to lose by imperial conquest. And like the Romans, the Inca relied on the cooperation of local elites to fill the imperial coffers.

The Inca policy of gentle persuasion involved taking provincial hostages to the Inca capital, Cuzco, to live in great style. These guests were steeped in the city's language and culture. Undoubtedly, it would have been impressed on them that the treatment they received depended entirely upon their participation in extracting tribute from their homelands. Garcilaso de la Vega, whose mother was a member of the Inca elite and whose father was a Spanish nobleman, described the strategy of the Inca emperor:

> They also carried off the leading chief and all his children to Cuzco, where they were treated with kindness and favor so that by frequenting the court they would learn not only its laws, customs, and correct speech, but also the rites, ceremonies, and superstitions of the Incas. This done, the [chief] was restored to his former dignity and authority, and the Inca, as king, ordered the vassals to serve and obey him as their natural lord.
>
> The Inca bestowed . . . gifts on newly conquered Indians, so that however brutish and barbarous they had been they were subdued by affection and attached to his service by a bond so strong that no province ever dreamed of rebelling. And in order to remove all occasion for complaint and to prevent dissatisfaction from leading to rebellion, he confirmed and promulgated anew all the former laws, liberties, and statutes so that they might be more esteemed and respected, and he never changed a word of them unless they were contrary to the idolatry and laws of his empire [*Royal Commentaries of the Incas,* translated by Harold Livermore, University of Texas Press, 1966].

The Aztec empire, centered in the capital city Tenochtitlán, also resembled republican Rome in its treatment of peripheral territories. In his recent book *Trade, Tribute, and Transportation* (University of Oklahoma Press), historical anthropologist Ross Hassig emphasized three correspondences in his analysis of the Aztec empire before and during the Spanish conquest:

> While the similarities between the Romans and the Aztecs can be overstated, they did share certain characteristics: (1) expansion of political dominance without direct territorial control, (2) a focus on the internal security of the empire by exercising influence on a limited range of activities within the client states, and (3) the achievement of such influence by generally retaining rather than replacing local officials.

When the Inca and Aztec empires fell to Spain, the conquerors seemed in a good position to replace the top strata of New World bureaucratic structures, leaving lower strata intact to funnel tribute upward. But substituting tribute to Spain for tribute to Cuzco or Tenochtitlán was a disaster for several reasons. Foremost, the


Smart people...

conquest brought massive loss of life through the introduction of Old World diseases. The indigenous economies were completely disrupted by epidemics that in many areas killed 70 to 90 percent of the population in less than a century, providing a grimly literal example of a shrinking tax base. In the New World, death and taxes were more closely linked than in the proverbial sense.

Second, the expanding European empire did not merely replace the top tier of the indigenous tribute system; it short-circuited the entire structure. Under the Aztec system, for example, tribute flowed through a pyramidal series of institutions, from local governments to regional centers to provincial capitals to Tenochtitlán. With the imposition of Spanish control, these intermediate stops were bypassed; tribute went from local regions directly to Mexico City and from there to Spain. Regional centers and administrative systems withered and disappeared, undercutting the native political order.

Finally, European governments and entrepreneurs were interested in forms of wealth that were tangible and transportable. Taxes in the form of labor—such as the Inca *mita* system, which supplied a work force for state projects—were less appealing. Thus, local groups that had previously met their obligations by working for the state from time to time were forced to pay tribute in goods.

As bad as this was, the situation was still worse for those New World people who were unaccustomed to life within the sphere of tribute-demanding empires. For them, being forced to pay taxes in the form of money or goods or labor was an impossible order: little or no surplus was generated by their subsistence economies, and no tribute-collecting mechanisms were in place. As a result, most of these peoples were pushed from their lands or trampled in the course of European expansion.

Today, of course, we enjoy the advantage of governing ourselves, instead of paying tribute to some foreign imperial power. And yet, as Thomas Paine observed in *Common Sense*,

> Government even in the best state is but a necessary evil; in its worst state an intolerable one; for when we suffer, or are exposed to the same miseries *by a government*, which we might expect in a country *without government*, our calamity is heightened by reflecting that we furnish the means by which we suffer.

*Samuel M. Wilson is an assistant professor of anthropology at the University of Texas, Austin.*

# First Dates

*The Maya calendar and writing system were not the only ones in Mesoamerica—or even the earliest*

by Joyce Marcus

At the time of the Spanish conquest, a number of peoples—the Aztec, Zapotec, Mixtec, Zoque, Maya, and others—occupied the region extending from central Mexico to as far east as Honduras and El Salvador. Although they spoke diverse languages and had distinct customs, they all shared what anthropologists consider a similar, Mesoamerican culture. While the Maya constructed monumental cities in the tropical lowlands of the Yucatán Peninsula, some of their best-known accomplishments had their origins among earlier societies located to the west of their homeland. Among these are the related phenomena of hieroglyphic writing and calendrical systems.

In Mesoamerica, writing first emerged among chiefdoms, societies that had hereditary differences in rank—based on the degree of kinship to the chief—but that lacked the division into exclusive upper and lower classes typical of ancient states, or civilizations. Between 3,000 and 2,500 years ago, a network of chiefdoms ran from the Valley of Mexico south through the present states of Morelos, Veracruz, Oaxaca, and Chiapas to the Pacific coast of Guatemala and El Salvador. The Maya who occupied the southern lowlands of the Yucatán Peninsula may have been relatively late participants in this network.

A wide range of materials and artifacts—including magnetite, jade, marine shells, obsidian, and pottery—circulated among the chiefdoms, probably as a result of trading and the ritual exchange of gifts on the part of high-ranking families. This interaction fostered a social milieu in which ideas traveled rapidly. For example, among the widely distributed items were pottery vessels with stylized motifs, such as lightning, that appear to have been linked to descent groups. The exchange of objects also reinforced political connections between chiefs, who formed alliances through intermarriage and cooperated in raiding rival chiefdoms.

A chief's authority was sanctioned by his supposed links to supernatural forces,

*This is the third in a series of articles that explore recent discoveries and interpretations concerning the rise and fall of ancient Maya civilization.*

rather than backed by real political power based on laws and arms. Nevertheless, a great deal of labor was coordinated for communal efforts, notably in constructing the massive pyramidal bases for temples. In Mesoamerica, the first carved stone monuments with hieroglyphs appeared in this context. They were erected, not in the Maya region, but in Oaxaca (inhabited by Zapotec-speaking people) and in southern Veracruz and western Chiapas (inhabited by Zoque-speaking people). Incidentally, the ancient Olmec of Veracruz and Tabasco, famed for their jade carvings and colossal basalt human heads—and once regarded as the "mother culture" of Mesoamerica—were already in their decline by the time writing came to the fore.

Some of the early hieroglyphic monuments made use of a 260-day calendar, which was common to all Mesoamerican groups and probably originated long before it was first recorded in stone. This calendar was produced by combining twenty day names with the numbers 1 through 13. A counting system based on twenty (perhaps originally derived from the twenty digits of the hands and feet) was used by all Mesoamerican Indians, while the day names, based on animals and natural phenomena, varied somewhat from group to group. Thirteen, far from


Joe LeMonnier

being unlucky, was an auspicious and sacred number. The combination of a given number and day name formed a unit that could not recur until 260 days (20 × 13) had elapsed. The calendar as a whole served ritual purposes, such as scheduling events for favorable days or divining the destiny of a child born on a certain day.

So important was this 260-day calendar that among peoples such as the Zapotec, Mixtec, and Aztec, children were often named for the day of their birth, resulting in such names as 2 Wind, 3 Crocodile, 5 Flower, 6 Monkey, and 8 Deer. To give the day name, a hieroglyphic sign was used; to give the number, most groups (including the Zapotec and Maya) used a dot for the number 1 and a bar for the number 5. Thus, "8 Deer" would be written with one bar, three dots, and a picture of a deer's head. Among the Maya, the number was placed to the left or above the day name.

Because calendrical glyphs were so common in Mesoamerican inscriptions—and were the first signs deciphered—scholars such as Sylvanus G. Morley and J. Eric S. Thompson once assumed that many pre-Columbian monuments recorded only calendrical information and that the Maya "worshiped time." But the Zapotec, Maya, Aztec, and others used the calendar to place both real and mythical events in time. Very early on, Mesoamerican chiefdoms depicted members of the elite and captives taken in combat, inserting the calendrical names of the persons portrayed.

Subsequent Mesoamerican writing systems continued to record the taking of rival lords and other captives and to honor victors in battle. In later states, which were larger and more socially stratified than chiefdoms, the themes of territorial control and personal aggrandizement were added. With the emergence of a dis-

Joyce Marcus

*Monument 3 from San José Mogote*

tinct noble class, writing became a tool of the state. Its content then expanded to include royal genealogies, ancestor worship, and important events in the rulers' lives, such as birth, marriage, and accession to the throne.

The earliest-known stone carving to display elements of the 260-day calendar is Monument 3 from San José Mogote, located in the Valley of Oaxaca only nine miles north of the ruins of the ancient Zapotec city of Monte Albán. This carved stone is between 2,600 and 2,500 years old (its age can be estimated because it lies beneath a dated floor and is associated with a certain type of pottery). It shows what appears to be a naked sacrificial victim sprawled in an awkward position, eyes closed, mouth open, with a stream of blood flowing from his open chest following removal of his heart. (These pictorial conventions appeared at a later date in Maya monuments.) Between the feet of the figure is inscribed the Zapotec day sign for "earthquake," placed above an ornate dot. This inscription, 1 Earthquake, was probably the victim's calendrical name.

As a result of competition for land, tribute, and water, rival settlements engaged in raiding, and prisoners so taken were commonly sacrificed to insure supernatural favors. This may have been the fate of 1 Earthquake. His name was proclaimed for all to appreciate, perhaps simply because he was a chief or other important person, perhaps also to identify the town that had been raided. This custom prevailed in later times among the Maya and other groups, but whether the victims were members of the same ethnic group as the captors or belonged to a different one is rarely easy to determine.

Monument 3 was laid flat on a bed of slabs at the entrance to a forty-foot-long corridor between two large public buildings, where anyone passing through would tread on the carved representation of the sacrificed captive. The image of a conqueror stepping on the body of a captive was another convention later borrowed by the Maya, who carved stone prisoner galleries and impressive monumental displays of political propaganda. The Maya depicted prisoners as the pedestals on which rulers stood; they also carved the risers and treads of stone staircases with images of bound prisoners lying full-length, which the ruler would ascend on the way to a palace or temple.

Perhaps a century after Monument 3 was carved, one of the earliest public buildings in the Zapotec city of Monte Albán was completed. It featured a gallery of more than 300 carved representations of naked captives. At this time, the first pure texts appeared, containing both calendrical and noncalendrical glyphs without any pictorial scenes. Significantly, some inscriptions, such as that on Stela 15 at Monte Albán, include calendrical signs (recognizable by their style and format) with numbers between 14 and 18. The great Mexican scholar Alfonso Caso interpreted these signs as the first evidence of a Mesoamerican 365-day calendar. Such a calendar, well-known from later sites, was divided into eighteen "months" of twenty days and a final interval of five days. Caso argued that the calendar signs with numbers greater than 13 must have been month signs (many later examples follow this method of naming the months).

These early Zapotec monuments suggest that the 260-day calendar may have been the first used in Mesoamerica, and that the 260-day and 365-day calendars were used side by side at least 2,400 years ago. Subsequently, the two sequences were used in interlocking combination to produce a cycle of dates that did not repeat for fifty-two years. This system set the stage for a still more comprehensive method of reckoning time, the so-called Long Count calendar. This calendar, for which the later Maya are famous, first appeared in a series of monuments in a region some linguists have assigned to Zoque-speaking Indians.

Somewhere in southern Mexico prior to 36 B.C., people had begun to use multiples of a 360-day "year" to produce a very accurate calendar for measuring long intervals of time. The Maya version of that calendar used as its starting point a date corresponding to August 13, 3114 B.C., of the Western (Gregorian) calendar. Some scholars have speculated that this base date was of mythological significance, calculated to coincide with the creation of the present world. From that starting point, the Indians tabulated the elapsed time in order to place events in an unambiguous temporal context.

Long Count dates were recorded with a string of numbers whose value depended on their position in the string (as in the Western system of ones, tens, hundreds, and so on). This efficient notation included a "completion" symbol to be used, when needed, as a place holder (accordingly, the Indians of southern Mexico are credited with independently inventing the concept of zero). Using this position-value notation (top to bottom or left to right in the case of Maya monuments), five different orders of time were recorded, in descending size. They began with the largest unit, a cycle of four hundred 360-day years (144,000 days). The next unit consisted of twenty 360-day years (7,200 days). The third unit was the eighteen-month year (360 days). Then came a month of 20 days, followed by the smallest unit, the individual day.

Stone monuments erected at four different sites—Chiapa de Corzo, Tres Zapotes, El Baúl, and Abaj Takalik—display dates that fall into the period that archeologists call Cycle 7. These are dates that lead off with seven of the 400-year units. Together, the four dates span 52 years, from 36 B.C. to A.D. 16. For example, Stela C from Tres Zapotes, Veracruz, records the Long Count of 7.16.6.16.18, using dots as 1 and bars as 5. In other words, the date is expressed as 7 cycles of 144,000 days, 16 units of 7,200 days, 6 years of 360 days, 16 months of 20 days,

*Stela C from Tres Zapotes*

Museo Nacional de Antropología, Mexico

and 18 additional days. If we assume that the starting date was August 13, 3114 B.C. (as it was for the Maya), this corresponds to September 3, 32 B.C., in the Western calendar. We do not know what important event was commemorated by the carving, since the rest of the text is heavily eroded.

None of these early sites lies within the area generally assigned to the Classic Maya. One falls in western Chiapas, one in southern Veracruz, and two on the Pacific coast piedmont of Guatemala. The first securely dated monument known from the Maya lowlands—the area where Maya civilization reached its peak—falls in Cycle 8. This monument is Stela 29 from Tikal, in the tropical rain forest of northern Guatemala. Its Long Count date of 8.12.14.8.15 corresponds to July 6, 292, in the Western calendar.

Another important date from about this time is found on a jade artifact called the Leyden Plaque, believed to have been carved at Tikal even though it was found more than 120 miles away. Its front depicts a noble, probably an early Tikal ruler, with a captive sprawled at his feet. On the back of the plaque is a Long Count date of 8.14.3.1.12, which corresponds to September 15, 320. What makes the Leyden Plaque so important is that it includes a verb that means "was seated" (in office), followed by the name of a ruler, his titles, and an "emblem glyph," representing the city or possibly the royal dynasty of Tikal. The plaque thus commemorated the day on which this ruler took office.

Justin Kerr

*The Leyden Plaque, presumed to be from Tikal*

Although the Maya knew of and used the 260-day ritual calendar, they apparently did not draw their names from it, as did their neighbors to the west and north. Most Maya rulers had names composed of other signs, including pictograms (such as animal heads, skulls, limbs, tails, weapons, or shields), ideograms (arbitrary conventions for such things as sky, earth, sun, or darkness), and phonograms, which transcribed their names phonetically. In the case of the Leyden Plaque, the Maya ruler's name features a bird's head with signs appended to the left and above that serve as modifiers.

Although the Maya were not the first Mesoamericans to use writing and calendars, through their contributions, hieroglyphic writing assumed its maximum versatility, complexity, and correspondence to a spoken language. We have yet to determine whether Mesoamerican writing had multiple origins or a single origin followed by rapid regional diversification. There are many more early texts out there still to be discovered. The long-neglected Zoque region of southern Veracruz and western Chiapas, which lies between the better-known Olmec, Zapotec, and Maya homelands, might provide the missing transitional stages between the earliest inscriptions and those of the Maya. □

*In an ancient southern Australian rift valley, a carnivorous allosaur strides along a stream bed as a labyrinthodont amphibian dips beneath the water's surface and hypsilophodonts retreat to vegetation along the bank.*

Paintings by Peter Schouten

# The Dinosaurs of Winter

*Neither cold nor dark of night stopped the hypsilophodonts*

by Patricia Vickers-Rich and Thomas H. Rich

The next to the last day of a long (and at times tiresome) 1987 field season got under way late when our team of excavators and rock bashers finally gathered at the site at about 9:00 A.M. No one was in much of a hurry, for after nearly two months of the same grueling work, you can't push yourself too hard too early, or you won't last past noon. Digging dinosaurs can be quite easy and also a great deal of fun if the bones happen to be abundant, well preserved, and exposed in soft sediments, such as clays or sands. Here at Dinosaur Cove, and at all the other localities producing dinosaurs along the southern coast of Victoria, Australia, fossils are not so easily won. Although the bones are exquisitely preserved, they are embedded in hard sandstones, siltstones, and claystones that can only be excavated using proper mining tools—jackhammers, big drills, and explosives. And for all our blasting and drilling, this field season had been a disappointment. Not many fossil specimens had turned up, and we were about to call it quits at this locality.

This season, the crew—many of them dedicated amateurs and volunteers—had dug two parallel tunnels into a cliff following an ancient stream channel in which bones had accumulated more than 100 million years ago. Subsequently, we decided to link the two tunnels together by a cross tunnel, a most fortuitous decision, for only in this third tunnel was much of consequence ultimately found. After blasting and drilling away the overlying rock, the crew gently took up the fossil-bearing layer from the floor of the "dinosaur mine," handling even the sharpest and heaviest rocks like newborns.

On this penultimate day, a crew member examining a recently split rock for a second time spotted a most unusual specimen in the gray light of the tunnel. Not surprisingly, it had been overlooked at first; the tunnels were not only dark but also muddy and cramped, and the specimen itself was dark brown against the encasing dark gray rock. The find proved to be the top of a fossilized skull of a dinosaur that could have been no larger than a chicken. A fresh break suggested that there was more to the specimen than we had found. A frantic effort soon led to the recovery of the missing counterpart, a fragment of the skull roof that during excavation had been peeled off like an orange rind. The imprint of the top of the brain—a large brain for a dinosaur—was clearly visible. What was more, the optic lobes, those parts of the brain dedicated to sight, were huge. Later we learned that in no other dinosaur of its kind—and in few dinosaurs of any kind—were the optic lobes prominent enough to have made a distinct impression on the skull roof.

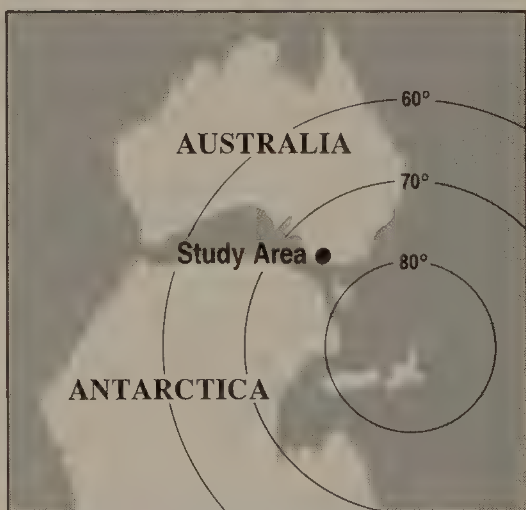
That day we were in luck three times: We found the specimen in the third tunnel after the first two had yielded almost nothing. We recovered all of what had been preserved of the skull. And as we dug out the tunnel, a drill hole with a diameter about the same size as the skull had missed the fossil by a mere four inches.

The next day, we were lucky a fourth time, for less than three feet from the skull fragments, we found the remnant of a leg and a significant part of a backbone and pelvis. Our first impression was that these bones were just the right size for our dinosaur, and subsequent lab work and fossil comparisons have largely borne this out. This brainy, large-eyed dinosaur, which lived about 106 million years ago, turned out to be a new species of hypsilophodont, a small, swift, bipedal plant- and insect-eater. We eventually dubbed it *Leaellynasaura amicagraphica.*

One would imagine that finding such a specimen after two months of nearly fruitless effort would release a joyous pandemonium among the crew. However, it was quite unlike that. After searching so long and so hard, we were emotionally numb, and only gradually did we realize that we had uncovered an important clue to life in this area about 106 million years ago.

Australia's fossil record of dinosaurs, and terrestrial vertebrate life in general, from about 220 to 65 million years ago, is almost nonexistent. The first dinosaur bone from the Victorian coast was discovered by a geologist about 1900. Eighty years passed before another dinosaur bone surfaced. The emergent mammalian fauna of Australia of this time is represented by just two jaw fragments. Numerous trackways and the rarer fossil bones support the notion that dinosaurs were abundant and dominant in Australia, but the evidence available until now has been exceedingly sparse, affording us merely a glimpse of life at that time. Ever since the 1960s, when we were university students working at the American Museum of Natural History in New York, we had wanted to find some pieces that would fill in this

Joe LeMonnier




*One hundred and six million years ago, Dinosaur Cove lay close to the South Pole. The land masses of what are now Australia and Antarctica were not yet separated by the Southern Ocean, and shallow inland seas covered portions of Australia.*

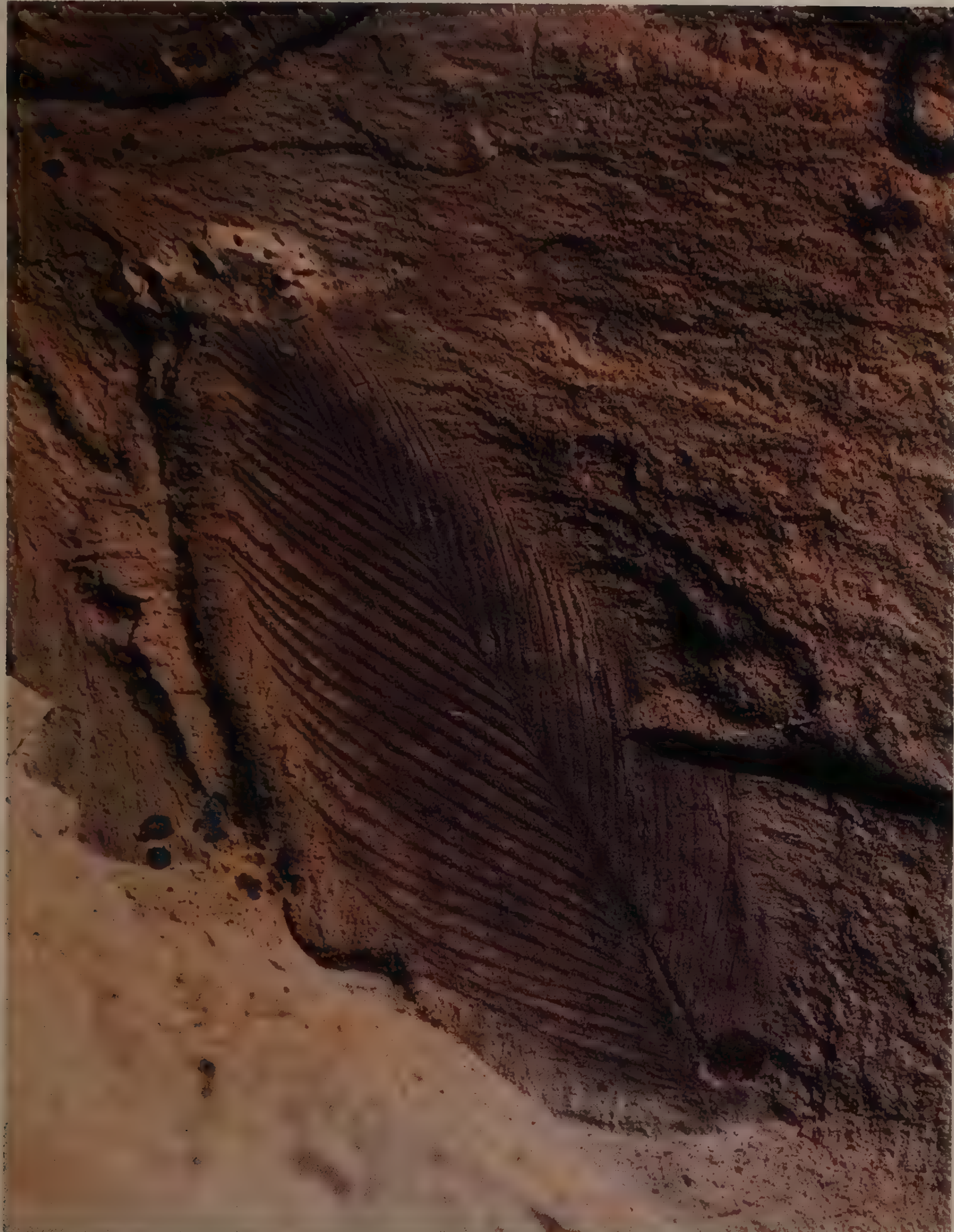
part of the Australian puzzle, to broaden the glimpse to a gaze.

Dinosaur Cove is situated in one of the prime places in southern Australia for recovering fossil bones. Along the coast, rocky outcrops in the Strzelecki and Otway ranges, southeast and southwest of Melbourne, have escaped deep weathering and the fossils they bear have not been subjected to the chemical erosion typical on much of the continent. The entire area of these coastal, dinosaur-bearing rocks in Victoria is a single square mile. The pounding action of the waves tears away at these rocks, exposing, but not dissolving, dinosaur bones. Only about 300 feet inland, the same kinds of rocks are so deeply weathered as to make hunting for fossil bones a futile exercise.

Today, from Dinosaur Cove the view to the north is of the low Otway range and to the south, the open expanse of the Southern Ocean. More than 1,800 miles away lies Antarctica. When the dinosaurs were living here, however, the scene would have been quite different. The Southern Ocean did not exist. Rather, the area was the floor of a rift valley. Australia and Antarctica, long fused as part of the great southern continent of Gondwana, were just beginning to separate from each other. At that time, one could have walked to Antarctica from the spot that is now Dinosaur Cove. The floor of the rift valley was almost flat, with perhaps a distant view of the Australian valley wall on the far northern horizon.

One hundred and six million years ago, in the early Cretaceous, southeastern Australia lay well within the Antarctic Circle of the day, perhaps as far as 80° south latitude. From the fossils of plants and invertebrates collected at Dinosaur Cove and other contemporaneous Victorian sites, we know that the climate then, while not as frigid as the polar regions today, was far from equable. Fossilized trees contain prominent rings, reflecting marked seasonal shifts. Oxygen isotope ratios determined for the rocks at Dinosaur Cove suggest that the mean annual temperature in southeastern Australia in the early Cretaceous was not higher than 41° F, and perhaps as low as 21° F. Summer tem-

*The well-preserved fossil skull of a chicken-sized, herbivorous dinosaur,* Leaellynasaura amicagraphica, *left, retains the impression of a large brain (at bottom) with huge optic lobes. Evidence of ancient bird life in southern Australia comes from fossil feathers. Below: One of the feathers found in fossil beds at Koonwarra is less than an inch long.*
Photographs by Steven Morton and Frank Coffa



peratures might have been quite warm, but during the long winter nights the air must have been well below freezing. Studies of ancient river valley sediments in the area point to periodic flooding, perhaps the result of runoff of seasonal meltwater from snowfields at higher elevations. (A decade ago, polar dinosaurs were unrecognized in either hemisphere, except for some footprints from Spitsbergen. Since then, a massive concentration of fossil bones, primarily those of duck-billed dinosaurs, has come to light on the Colville River on the North Slope of Alaska. Additional discoveries of isolated specimens in both hemispheres—including Alaska, Canada, Siberia, New Zealand, and the Antarctic Peninsula—hold promise of providing a much broader picture of high-latitude dinosaurs in years to come.)

Nevertheless, Dinosaur Cove and its environs supported abundant life in the Mesozoic. The new hypsilophodont fossils were among the most intriguing of a variety of plant and animal remains of similar age uncovered in Victoria in the late 1970s and the 1980s. We now had a better opportunity to reconstruct the ancient polar environment and to try to determine how the creatures of Dinosaur Cove, particularly the dinosaurs, could have coped with long, warm summer days and equally long, cold winter nights. To begin with, we placed the hypsilophodonts in context, piecing together a picture of their polar world.

The work thus far on the Victorian dinosaurs and their associated flora and fauna has revealed more than 150 different species, from spiders to pterosaurs, ferns to conifers. The landscape was relatively green and lush, given its geographical location. Large, nonflowering plants, including monkey puzzle trees, ginkgoes, and podocarps, dominated the flora. Ferns abounded, with some types sharing the undergrowth with bryophytes and other low-growing vegetation, and with other kinds proliferating on the forest fringes. *Lycopodium,* a primitive vascular plant, and sphagnum mosses grew in more open moorlands, while quillworts, hepatics, and algae dominated the aquatic environments. A few rare species represented the new tribe of flowering plants. By the time the dinosaurs became extinct about 65 million years ago, flowering plants had come to rule the terrestrial flora, but in southern Victoria more than 100 million years ago, they would have hardly been noticed in an otherwise uniformly green plant community.

Modern relatives of many of these plants are found in the mountains of southeastern Australia and in Tasmania's high country, where they are often covered with snow during the winter. While they also inhabit some warmer climes, their habitat range suggests that their Mesozoic ancestors could have coped with winter conditions at what is now Dinosaur Cove.

More than eighty species of invertebrates are also associated with the dinosaur faunas. Most come from one remarkable locality, Koonwarra, in the Strzelecki range to the southeast of Melbourne. Spiders, freshwater bryozoans, shellfish, and what are possibly earthworms, along with a diversity of crustaceans, have been

*A variety of hypsilophodonts, including agile, large-eyed* Leaellynasaura *(foreground) and the larger* Atlascopcosaurus *(top), foraged in the relatively lush, cool-temperate rain forests of early Cretaceous age in Australia.*

found in the ancient lake sediments preserved at Koonwarra. Of the twelve orders of insects present, the bugs, beetles, and flies are the most varied, and many immature individuals are preserved.

Antarctic Australia was also home to a variety of fish, including lungfish, which today have a very restricted range in the swamps and marshes of tropical Africa and South America, as well as the rivers of northeastern Australia. Several other bony fish groups, some rather primitive when compared with most living fish, inhabited these ancient rivers and streams.

Birds have left only feathers to signal their presence, but bones of amphibians, turtles, pterosaurs, and lizardlike reptiles, as well as teeth of the long-necked, Loch Ness "monster"-like plesiosaurs, have been found. Although most plesiosaurs were ocean dwellers, the Australian ones inhabited fresh water. Just as some seals and dolphins, for example the Ganges River dolphin, today sometimes invade rivers and lakes, so, too, must have some Cretaceous plesiosaurs. They were a long way from the nearest ocean.

An intriguing aspect of the fossil vertebrate fauna is that it contained several forms that had long since become extinct elsewhere in the world. These included the bipedal carnivore *Allosaurus* and the youngest surviving labyrinthodont amphibian, a large, semiterrestrial, carnivorous form. These vertebrates survived tens of millions of years beyond their time elsewhere. They were "living fossils" even in the early Cretaceous. Perhaps because of its polar location, Australia served as a refuge for many different kinds of animals and plants.

More than half of the approximately 200 dinosaur fossils recovered are those of juveniles. Dinosaurs were not just visiting the area occasionally; they were most likely using it as a nursery, taking advantage of the high productivity that such a polar area sustained during the summer months, when the sun shone twenty-four hours a day.

Large rivers, which eventually became choked with sediments, flowed across the early Cretaceous Victorian valley floor. Smaller, more gently flowing streams that fed into those rivers were ultimately filled with a mixture of clays and finer sands. It is in the latter that the rare fossils of vertebrates, most from diminutive creatures, are most frequently found. Nevertheless, larger dinosaurs were present, a fact established by the finds of a few isolated bones. In every case, these were the smallest bones on which it is possible to base the identification of the larger animals, and frequently, these specimens appear to have been from juveniles. Even the carnivorous allosaurs were small in stature compared with specimens in North America, for example. This trend holds for the hypsilophodont dinosaurs, too; the tallest reached only the size of a human of medium height.

The herbivorous dinosaurs were all hypsilophodonts, like *Leaellynasaura amicagraphica.* Elsewhere in the world, hypsilophodonts are generally a rare element in museum fossil collections, and typically only one or at best a few different kinds are known in one area and of one age. In southeastern Australia, the quantity of material, although small, indicates that up to five different species of this single family may have been living here, all at about the same time. Members of this family seem to have thrived at this polar latitude. Did they survive the winters by migrating or perhaps by hibernating? Or did they remain active even during the most stressful times of the year?

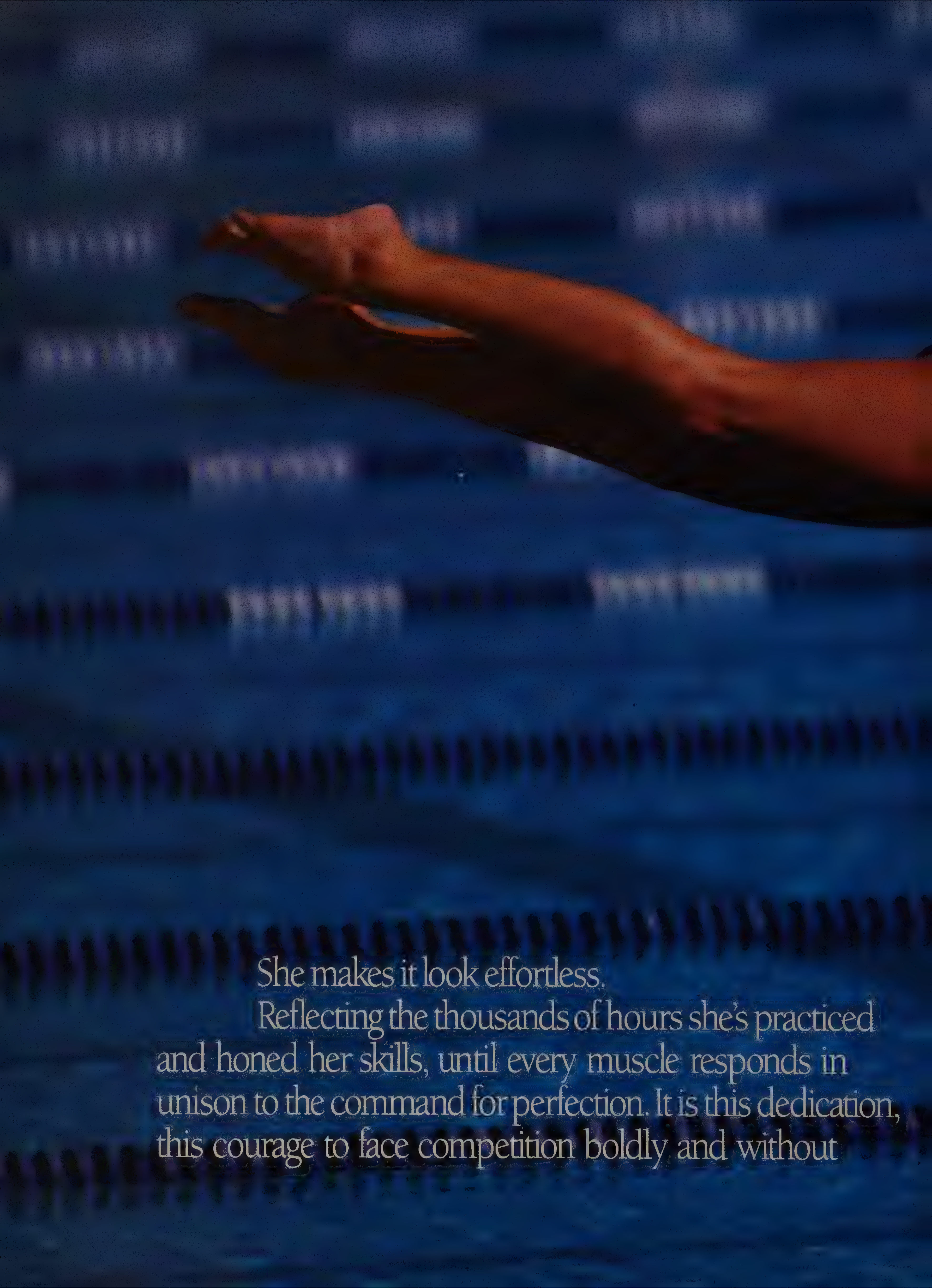
A look at a paleogeographic map of Australia for this period indicates that migration to lower latitudes would not be a simple matter of going directly north. Because of the shallow sea that covered much of northeastern Australia, to reach the Antarctic Circle (and thus some daylight every day of the year) on dry land would have required migrating to the northwest about 600 miles. Although modern caribou do migrate a comparable distance in the Northern Hemisphere, no smaller terrestrial mammals the size of *Leaellynasaura* do. And in any case, at the Antarctic Circle on the shortest days of the year, the sun will shine only briefly on the southern horizon at noon.

Although reptiles do live north of the Arctic Circle today, they accomplish this by burrowing into the mud and hibernating. Even in temperate climates, modern reptiles cease to be active when the daily average temperature approaches freezing. The clue to the hypsilophodonts' winter habits, and the answer to the hibernation question, may lie in these dinosaurs' large brains.

Why would *L. amicagraphica* have developed particularly prominent optic lobes on its brain, while members of its family from other continents did not? Of all other dinosaurs, only the "brainiest" ones, the small carnivores such as the North American *Troodon,* could match it. Sharper sight seems to be the most plausible answer. The only prominent difference between this dinosaur and the other members of its family is where it lived: close to the South Pole of the day. Presumably, the enhanced eyesight would not have been needed during the polar summer, when plenty of light was available. If this unusual ability was required because of the low light levels encountered during the winter, it would imply that *Leaellynasaura* was active even during winter, when the temperatures were probably below freezing for prolonged periods. This idea, in turn, lends support to, but by no means proves, the hypothesis that some dinosaurs were warmblooded.

Intensive prospecting and excavation since the late 1970s have produced remarkable assemblages of flora and fauna that are altering our views of world climates 100 to 120 million years ago. Even though temperatures were, in general, globally higher, polar areas most certainly experienced low temperatures and seasonal fluctuations that would have been quite stressful to living things. Some dinosaurs, however, were able to cope with these conditions. Understanding just how they coped and under what conditions they lived will undoubtedly contribute to understanding why dinosaurs, as a group, disappeared at the end of the Cretaceous. Dinosaurs and other creatures that survived in south polar climes 106 million years ago may also give us a better estimate of when, and how rapidly, the changes leading to our modern glacial climate took place. □


PETER SCHOUTEN 88



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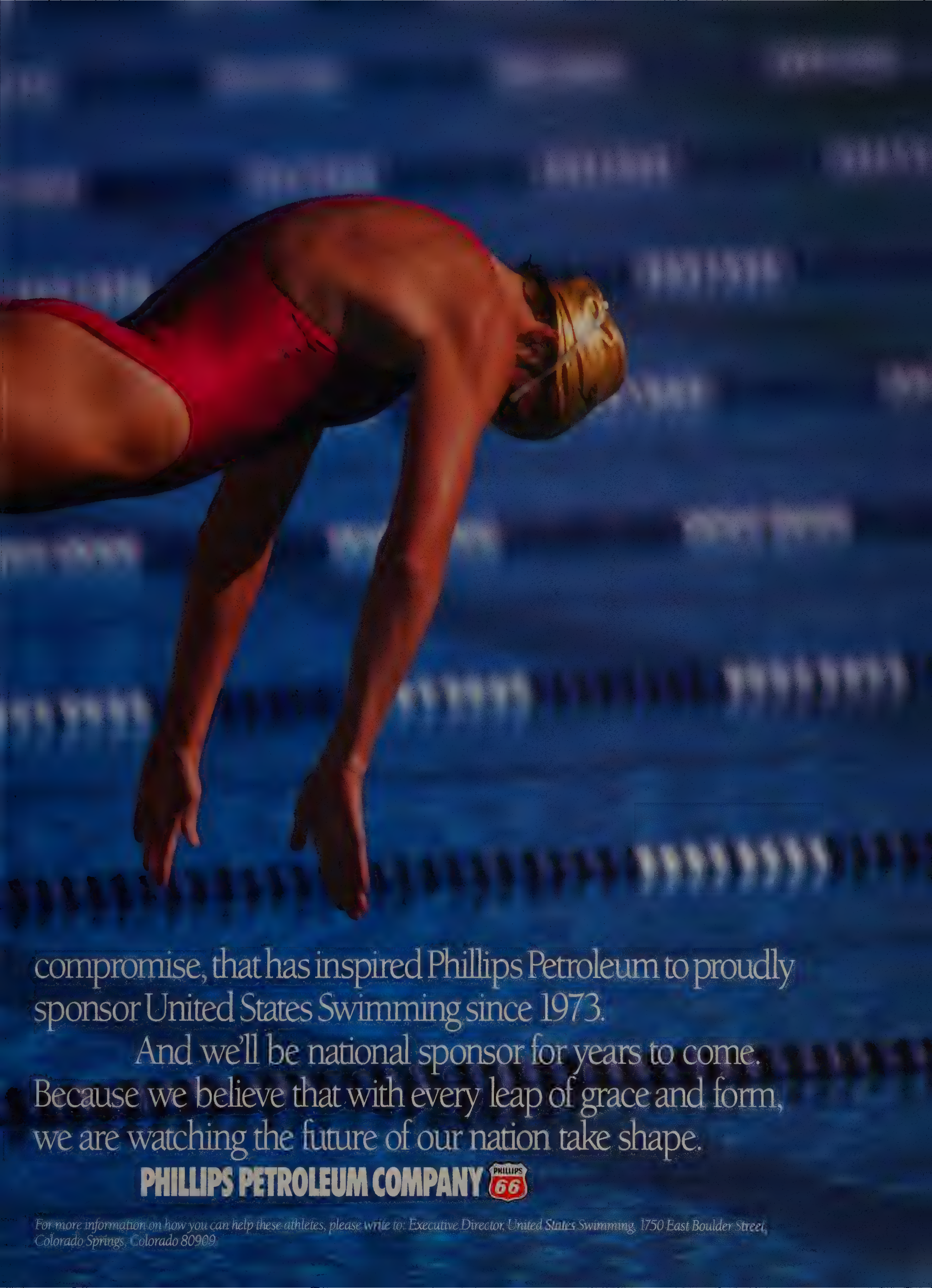
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And we'll be national sponsor for years to come. Because we believe that with every leap of grace and form, we are watching the future of our nation take shape.
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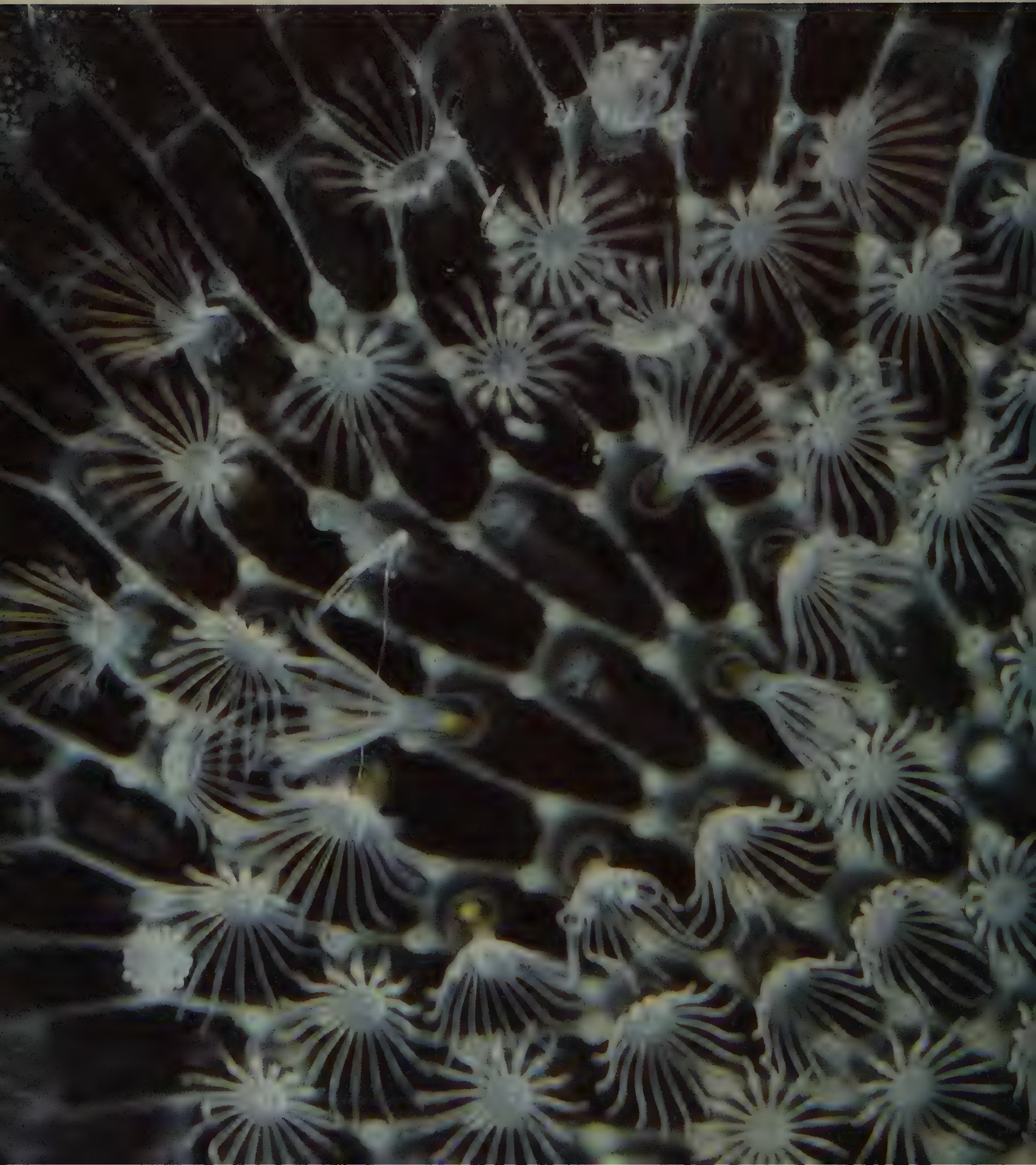
For more information on how you can help these athletes, please write to: Executive Director, United States Swimming, 1750 East Boulder Street, Colorado Springs, Colorado 80909.

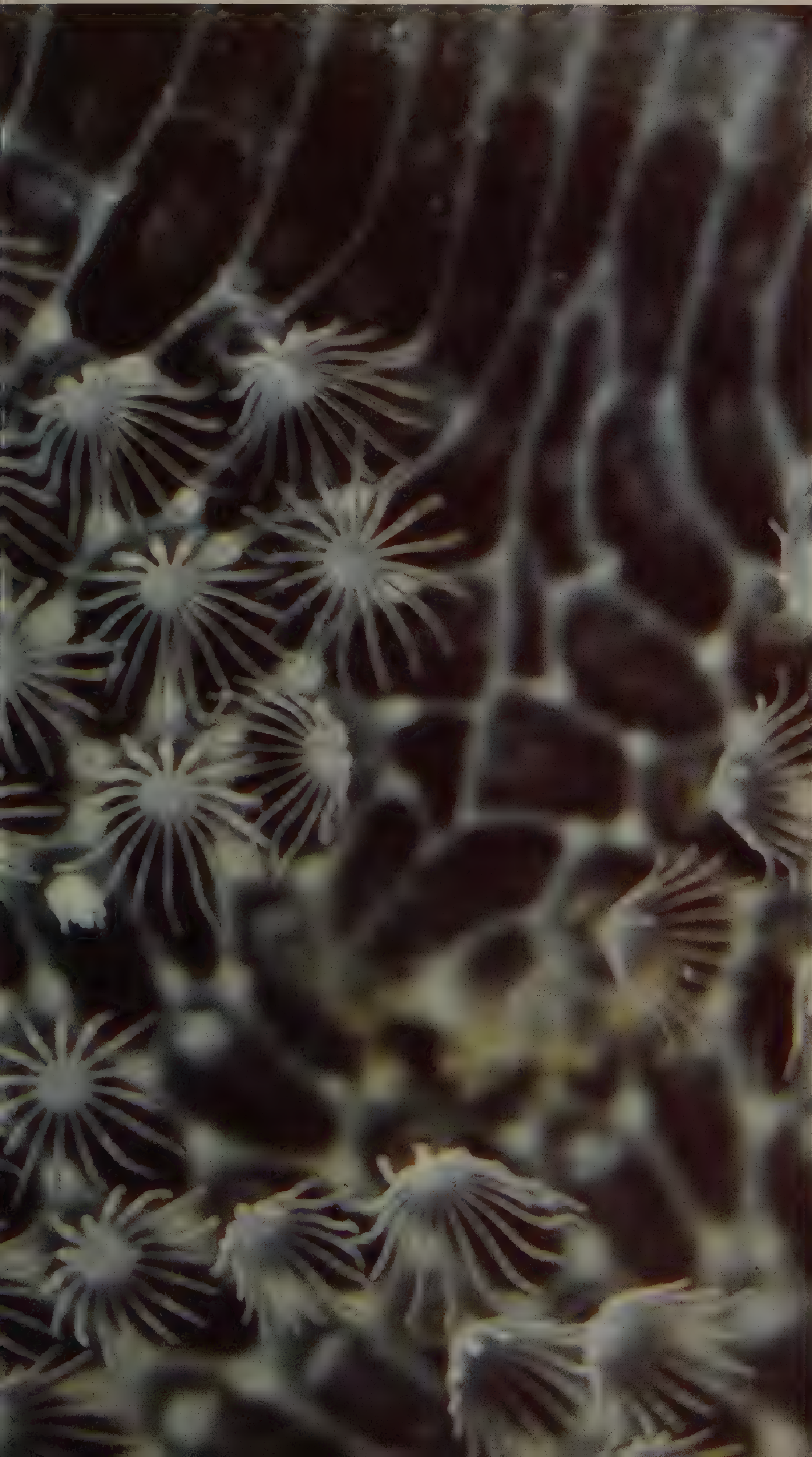
*Most of its lophophores extended and waving, a colony of* Membranipora membranacea*—also known as common sea mat or lacy crust bryozoan—feeds by filtering plankton from the water.*
Colin Milkins; Oxford Scientific Films



# Turbulent World of Moss Animals

*Common but little known, bryozoans can be found from the sea's edge to the abyssal depths*

by Christopher G. Reed

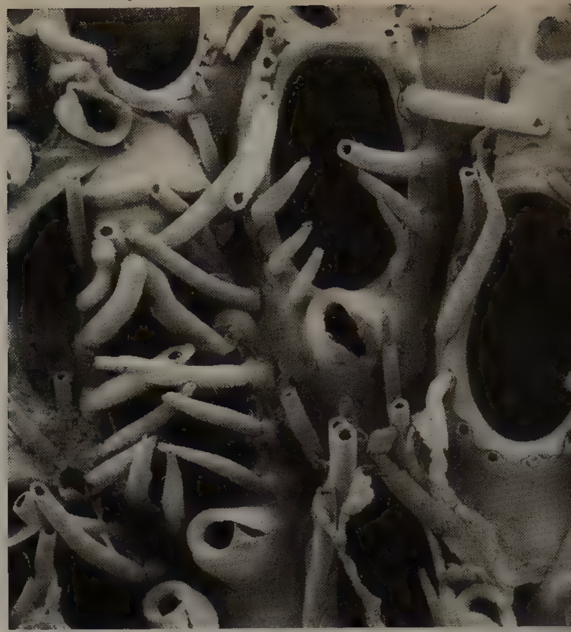


Imagine that you are standing in an orchard in winter, the leafless branches of its trees forming a canopy overhead. The branches are in constant motion, buffeted by an unseen, turbulent wind that is drawn downward through the limbs and swirls over the ground around you. Now imagine that the wind is generated by the branches themselves, and that birds and insects are being sucked into a vortex above each tree and into a central gullet, where they are devoured. If you change the medium from air to water, you are visualizing a bryozoan colony. Except that the "orchard" is measured in inches, rather than acres, the "trees" are only one-fiftieth of a inch tall, and the living things being eaten are microscopic algae, bacteria, and flagellates. Bryozoans are among the most common invertebrates in the marine environment. But most people are unaware that the animals exist. The problem is that while bryozoan colonies are easy to see on rocks and algae, the individual members of the colony are microscopic.

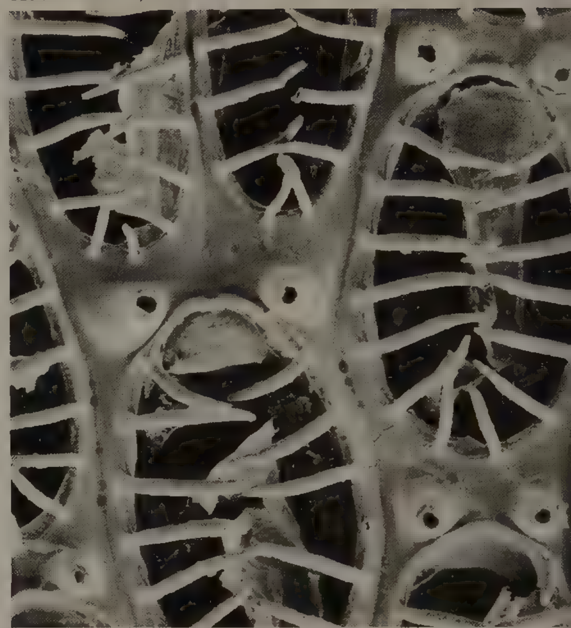
Bryozoan colonies range from mossy feltworks to bushy arborescences to calcified incrustations to elevated, curled, leaflike growths that have the appearance and consistency of a handful of potato chips. They were first correctly identified as animals by an eighteenth-century French medical student, Jules Peysonnel, who was studying marine biology off the Ivory Coast. Peysonnel wanted to present his discovery to the French Academy of Sciences, but he wasn't allowed to address the academy because he wasn't a member. Instead, he asked a friend who was a member, René-Antoine Ferchault de Réaumur, to present the novel findings at the next meeting. Upon reading Peysonnel's paper, however, Réaumur decided its view deviated too radically from that expressed by Linnaeus and suppressed it to protect the reputation of his young friend. As a result, Peysonnel's account was never published, and he never received the proper recognition for his discovery, which was outlined in detail two decades later by an Englishman named John Ellis.

The stationary colonies of bryozoans

Kathleen B. Sarg; AMNH



Judith E. Winston; AMNH



are composed of thousands of minute individuals called zooids, which, in incrusting forms, look like so many tiny marble coffins lined up next to one another. Each zooid consists of a calcified box, or zooecium, containing a digestive tract and a feeding organ. The feeding organ, a circle of ciliated tentacles, can be extruded from the zooecium into the seawater above the colony. This circle of tentacles is called the lophophore—the tree in the orchard analogy—and the tentacles, covered with thousands of cilia, are the branches. Coordinated beating of the cilia produces the currents that draw food into the center of the tentacular ring. Because of the geometric growth pattern of the zooids, the lophophores are regularly spaced throughout the colony; this spacing is what makes the colony more of an orchard than a forest. At the base of the cone formed by the tentacles is the mouth, equipped with a muscular pharynx that dilates reflexively, sucking in planktonic plants and animals that have collected in the vortex created by the feeding current.

Some species swallow and crush the food organisms in a gizzard before passing them on to the stomach to be digested. The digestive tract is recurved, ending in an anus that opens just outside the lophophore. The digestive tract and the lophophore are known as the polypide of the zooid; it can be retracted in microseconds into the protection of the zooecium by a pair of retractor muscles. Now imagine that the orchard around you can disappear in less than a second, each tree drawn into a chamber in the ground, leaving only a field of stubble and an abrupt quiescence, as in the eye of a hurricane.

I learned about the retractor muscles of bryozoans as a graduate student at the University of Washington. I was searching for a dissertation topic and was considering examining the ultrastructure of the lophophore of a local bryozoan. One night at the Friday Harbor Laboratories, I set about to snip off the extended lophophores to prepare for electron microscopy. I had a fine pair of iridectomy scissors, but not a very steady hand. Every time I tried to sneak up on an extended lophophore, the polypide would retract just as I snipped, and I would end up with just the ends of the tentacles. Finally, I quit in frustration and retired to the library to console myself. There, in the most recent issue of *Science,* was an article describing the lophophore as having the fastest-known contracting muscles. Reinforced by this evidence, I took the journal to my adviser's laboratory to show him that there was a reason for my failure. As I entered, my adviser, Richard Cloney, was bent over his dissecting microscope, enveloped in a haze of cigar smoke. "I have something to show you," I announced.

"Just a minute—look at this."

I bent over the microscope. In a little dish he had cut off ten to fifteen lophophores from the same species I was working on. "Now," he leaned back in his chair and puffed majestically, "what did you want?"

"Oh, nothing," I said, cramming the journal into my back pocket. In retrospect, I think I can explain his success without impugning my competence. The only rational explanation must be that the nicotine from the pall of smoke in his lab narcotized the animals.

Comparing an orchard with a colony of bryozoans is not as far-fetched as it may seem. Bryozoans share many characteristics of plants, probably because both plants and sessile animals are unable to move their base of attachment and therefore have evolved similar defense mechanisms. Some trees—poplars and sugar maples, for instance—produce more tannin in their leaves in response to increased attacks by herbivores. This regulated chemical defense makes the plants less digestible to such insect grazers as the gypsy moth caterpillar.

Like clusters of sugar maples or orchards, bryozoan colonies are vulnerable to predators. In this case, the predation is partial, since the entire colony is seldom killed. The main enemies of bryozoans are sea slugs, or nudibranchs; these big, lumbering, tanklike organisms crawl over the bryozoans, sliming their surfaces and seeking their weak point. The Achilles' heel of most bryozoans is their frontal membrane, which the sea slug gnaws through by rasping at it with a sliding belt of sharp teeth called the radula. Once through the frontal membrane, the sea slug sucks out the polypide. What possible defenses might a bryozoan employ when confronted with such a terror? Some recent observations reveal that they don't just sit still.

One bryozoan, *Membranipora,* a species that incrusts brown algae and that is found all along the eastern edge of the Pacific Ocean, has been divided into species based on the patterns of spines on the zooids. In 1982, Paul Yoshioka, a biologist at the Scripps Institution of Oceanography, noticed that spiny colonies of *Membranipora* only occurred when nudibranchs were found in association with them. He therefore made the intriguing proposal that the various spine patterns reflected, not different species, but an individual colony's response to grazing by sea slugs. According to Yoshioka, the spines are physical defenses against the depredations of nudibranchs; like the tannins in sugar maple leaves, the *Membranipora* spines make the colony less attractive to foragers. Next, Drew Harvell,

*Scanning electron microscopy reveals spines on two Pacific species of bryozoan:* Callopora craticula, *top left, and* Membranipora angulata, *bottom left. Spines may grow in response to predators or other environmental factors. Below: The larva of the bryozoan* Dendrobeania lichenoides.
Christopher G. Reed

now on the faculty of Cornell University, followed Yoshioka's lead and demonstrated that colonies of *M. membranacea* were capable of forming spines within forty-eight hours of exposure to the nudibranchs.

Because of these discoveries of "inducible" defenses, the rich bryozoan fossil record, which only preserves the calcified skeletal parts of colonies, should be interpreted with caution. Rather than indicating separate species, the spine patterns may only reveal how much predation a particular colony had experienced back in the Mesozoic era. The ecological features of long-extinct communities, features that we have believed to be unknowable, may be recorded in the skeletal shapes of bryozoans.

Perhaps the greatest struggle for a bryozoan is finding enough space in which to live and grow. Plankton provides a virtually boundless source of nutrition, but bare space—whether on a rock or on the surface of an annual alga—is only fleetingly available in the marine world. Bryozoans vary in how well they compete for space. Within a single community on the underside of a rock or coral head, there may be a hierarchy in which one species overgrows another species, which is overgrowing yet a third variety. A colony of a single species may occupy space only ephemerally, growing out at the margins by the asexual replication of zooids in a radiating fashion, like a fairy ring of mushrooms or a ring of ferns, until it is overtaken by a superior competitor.

If you could speed up time, you would find the boundaries of your orchard constantly changing. You would see it growing around and even over orchards with different species of trees, or perhaps being overgrown in turn. When you look at the mosaic of different colonies of bryozoans on the underside of a rock in the intertidal zone, what you are really seeing is a silent, life-or-death struggle for space. And as in all warfare, the combatants may use any advantageous technique to remain alive. Some bryozoans grow spines not only to retard predators but also in response to superior competitors; the spines apparently enhance their ability to resist overgrowth. Others are readily overgrown from behind but are able to resist overgrowth if they meet the competitor at their growing margin. Some species even seem to be able to change their direction of growth when encroached upon by a superior competitor. Such observations raise questions; for example, how does the colony sense the presence of a "superior" species before contact has occurred?

Colonies of the same species are equal competitors but inhibit one another's growth by contact. In *M. membranacea,* each colony may send out a quick-growing, specialized zooid that forms a stolon—a stemlike, cylindrical structure—along the margin of the encroaching colony. The stolon inhibits the further growth of the competing colony, and the space on the near side of the stolon is essentially reserved for expansion of the colony that sent it out.

Other species may even form alliances with different kinds of animals. The incrusting bryozoans *Celleporaria brunnea* and *Schizoporella errata,* for example, have a symbiotic relationship with a small colonial hydroid, *Zanclea gemmosa,* that grows over the surface of the bryozoan colony and along its growing margins. The hydroid apparently receives increased protection from grazers because its own, rootlike stolons are covered by the calcification of the bryozoan, while the bryozoan benefits from the presence of the hydroid's stinging cells on polyps around the margin of the colony.

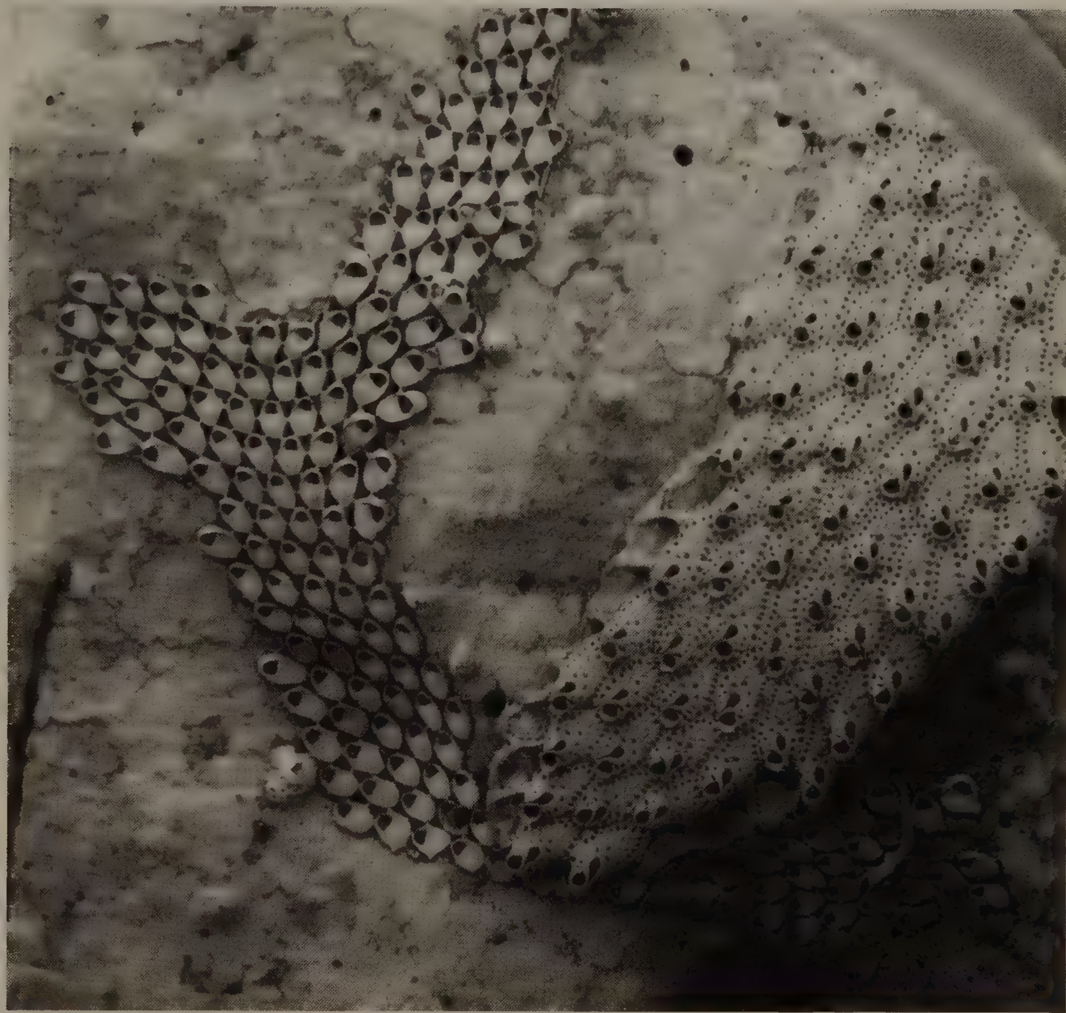
*Schizoporella* also protects itself with regularly spaced jawed zooids, called avicularia, that snap shut at the slightest vibration. These specialized members of the colony undoubtedly reduce the likelihood of the surface's becoming colonized by algae and larval invertebrates, although the symbiotic hydroid seems not to be deterred.

Once a colony of bryozoans is bounded by other colonies and can no longer spread by cloning itself, it shifts its energy into sexual reproduction. Clumps of writhing spermatozoa are released through the tips of the tentacles to be carried by water currents over other colonies of the same species, where they are drawn down into

Norbert Wu

*A large bryozoan colony, left, blankets a rock in the Sea of Cortés, Baja California. Below: Two Caribbean bryozoans compete on a piece of Jamaican coral:* Reptadeonella, *growing from right to left, is overtaking a colony of* Mollia. *Both species grow on the undersides of corals and in the caves of coral reefs.*

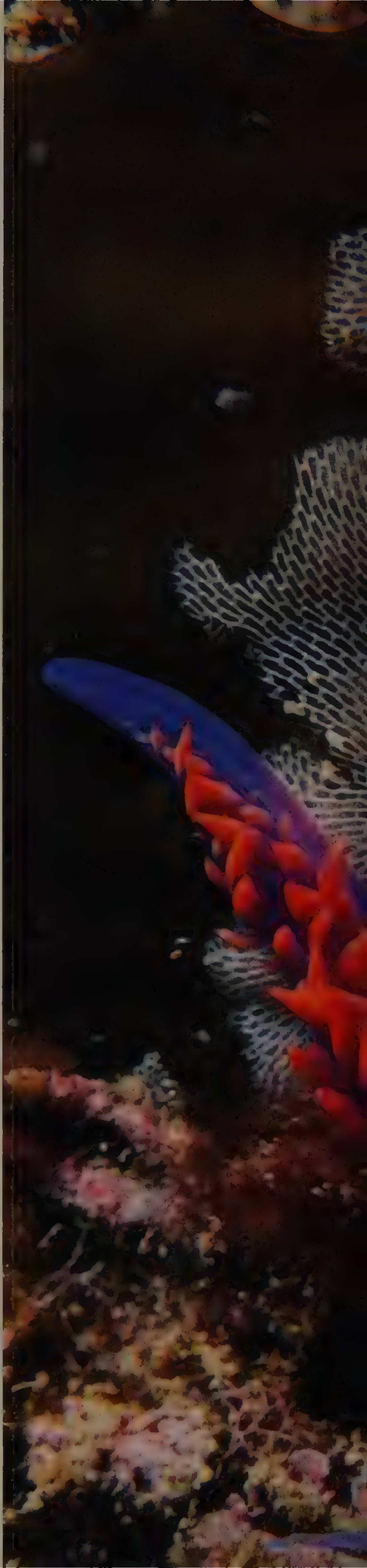
Barbara P. Worcester; AMNH



the feeding current of the zooids. But instead of being eaten, the spermatozoa attach themselves to the tentacles of the polypide. When an egg appears in a short, ciliated funnel at the base of the tentacles, the spermatozoa disengage themselves and swim down to the funnel, where fertilization is presumed to occur.

The situation just described occurs only in free-spawning species, of which *Membranipora* is an example. Most bryozoans, however, retain their eggs in elaborate helmet-shaped brood chambers, called ovicells, on the colony surface. In an "orchard" of *Schizoporella,* the brood chambers are specialized zooids, resembling geodetic domes, that erupt between the "trees." In each translucent, partly calcified ovicell is a heavily yoked, reddish embryo.

The larva that emerges from the ovicell following the embryonic period is a cilia-covered sphere ranging from .1 to .5 millimeter in diameter. It may be best visualized as an orange dipped in honey and then rolled on a barbershop floor; the rows of hairs (the cilia) all beat in synchrony, propelling the orange through the water. This highly organized, discriminating organism with its complex nervous system responds to light and gravity and exhibits specific preferences. The larva is choosy about where it will settle and what it will settle on to become the progenitor of the adult colony. Evolutionarily, this is a prudent adaptation, since the neighborhood a bryozoan finds itself in may determine the size and fecundity of the colony. Once the larva settles, it cannot pack up and move if the neighborhood goes bad. Some larvae can defer settling down in the presence of a superior spatial competitor, thereby reducing the likelihood of overgrowth early in the development of the colony. And some larvae settle only on a specific substrate, such as the blades of brown algae. These apparently maximize their potential growth as adults by settling preferen-



*Besides being overgrown by competitors, bryozoans face being destroyed by the depredations of shell-less snails known as nudibranchs. Here, a Pacific coast nudibranch, purple aeolis, grazes on a colony of lacy crust bryozoans incrusted on kelp.*
Susan Speck

tially on the youngest areas of the blades.

In our *Membranipora* orchard, the fertilized eggs, or zygotes, are initially shaped like biconcave disks. Spewed out into the seawater like so many Frisbees, the zygotes sail away to develop into peculiar triangular bivalved planktotrophic larvae. Known as cyphonautes, or little sailors, these beautiful, transparent larvae were initially thought to be rotifers, planktonic animals with a wheel of cilia, probably because they bear no resemblance to the benthic adult colony that they eventually become.

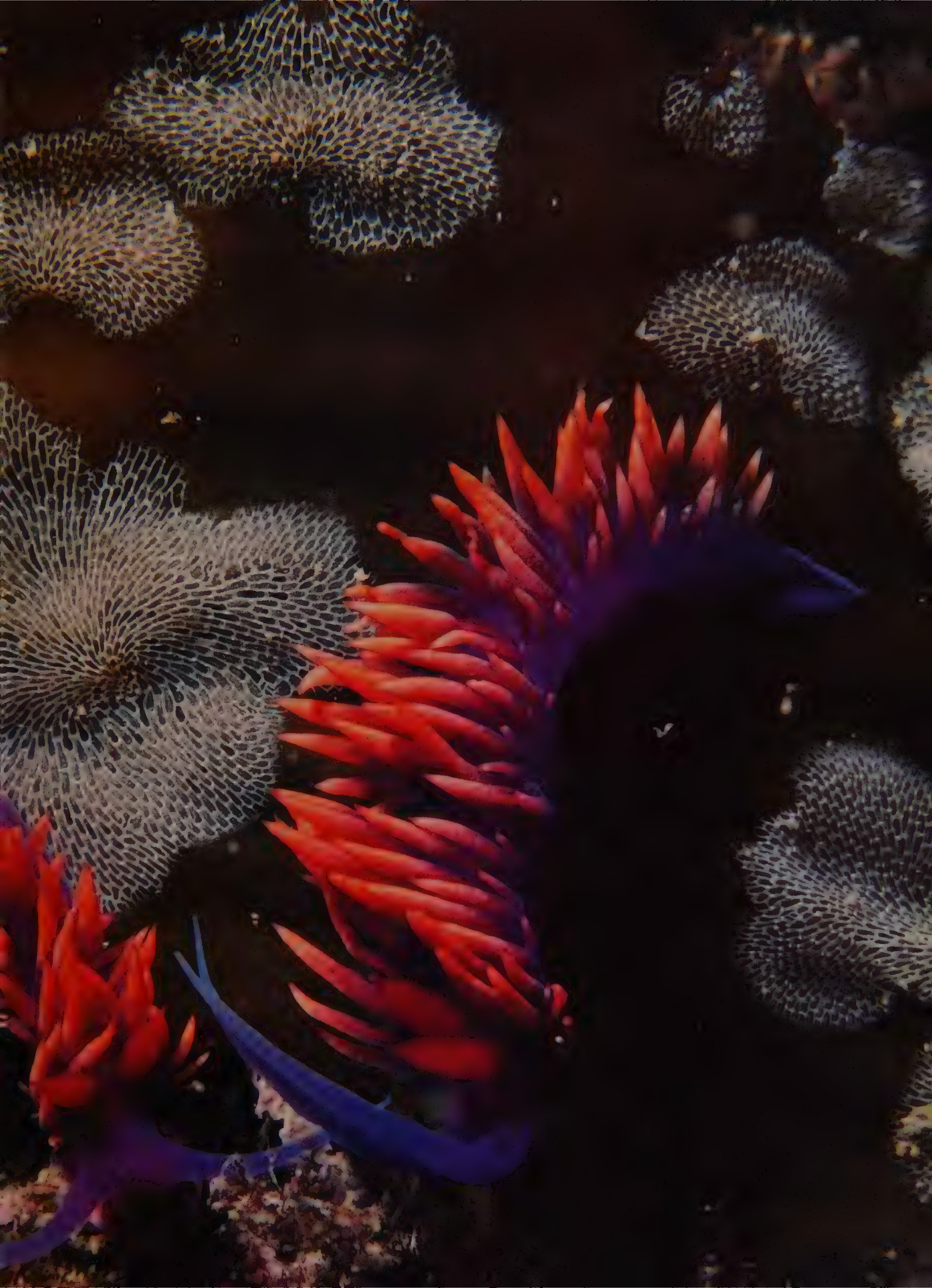
Metamorphosis transforms the free-swimming larva into the sessile progenitor of the colony, called the ancestrula (the first zooid of the colony). The sense of wonder and mystery that this process holds for those who are fortunate enough to observe it is reflected in the words of Thomas Hincks, a prominent nineteenth-century bryozoologist:

> The larvae are restless in their habits, and during their short term of free existence are in almost constant movement, now whirling rapidly hither and thither, now tumbling over and over in the water, now creeping along, making use of their cilia as feet. Besides their ciliary appendages, they are often furnished with long setiform processes, which wave to and fro, and lash the water with much vehemence. After a while their energies fail, and they settle down and become attached; the cilia begin to flag in their movements, and soon disappear; and the volatile and curiously organized being resolves itself into a fixed and (apparently) homogeneous mass, in which the first zooecium and polypide originate.

Hincks's description illustrates the sharp contrast between the motile, vibrant, free-swimming larva and the sessile, apparently quiescent juvenile. The rapid transformation and massive degeneration of larval tissues led most early investigators to view bryozoan metamorphosis as a completely destructive process. The adult organs were thought to develop *de novo* from this amorphous mass.

But this is not the case. Bryozoan larvae have organs specifically adapted for swimming through seawater, selecting an appropriate substrate, and attaching. They are equipped with larval locomotory and sensory organs consisting of ciliated regions of the larval epithelium. The adult epidermis, or skin, is tucked away in invaginations, dormant, awaiting the moment when it will be needed. This moment is metamorphosis. At the onset of metamorphosis, the larva absorbs its larval skin and covers itself with the adult skin by a series of rapid movements that essentially turn it inside out within minutes. At the same time, the adult skin begins secreting the protective calcified exoskeleton (the zooecium). The digestive tract of the first polypide also begins to differentiate, drawing nutrition from the degeneration of the yolk-laden larval tissues. Far from being a period of quiescence, this is a time when adult structures are developing and differentiating while unneeded larval tissues degenerate. Suddenly a mobilization of phagocytes—scavenging cells—engulfs and digests the larval tissues. These simultaneous processes of cell death and cell rejuvenation, side by side in the same organism, remain a fundamental mystery to developmental biologists. How do the phagocytes distinguish between cells destined to die and those destined to live? What controls the clock that synchronizes these processes into the recurrent patterns of metamorphosis that we observe in so many different species? A plethora of mysteries remains to be explored in this little-known phylum.

The turbulent world of bryozoans is a shady, shadowy twilight world—undersides of rocks or floats where competition with marine plant life is minimal. Suddenly, as the twilight is shattered by brilliant sunlight, the lophophores struggle in vain to extend themselves to extract food from the life-giving seawater. But the medium has changed, and the lophophores are now exposed to the air. The temperature slowly rises, baking the exposed zooids and leaving the dry and lifeless skeleton of the colony bleaching in the midday sun. Strolling farther down the beach, the person responsible for these new conditions leaves other rocks overturned, unaware or perhaps unmindful of the catastrophic consequences to the microcosmos beneath. □



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*A fountain of molten rock hundreds of feet high sends rivers of lava flowing down the slopes of Kilauea in Hawaii.*
Douglas Peebles

# Ancient Floods of Fire

*Today's volcanic eruptions pale in comparison with those in the geologic past that sent seas of lava across the earth*

by Robert S. White

For almost a week, severe earthquakes had rocked southern Iceland. Then, on the morning of June 8, 1783, the ground southwest of Mount Laki split open along an eight-mile stretch. Incandescent fountains of lava erupted from dozens of vents along the fissure, spewing molten rock at a rate surpassing the flow of water over Niagara Falls. The landscape of green grasses disappeared beneath a blanket of fiery, reddish orange rock, which rapidly acquired a crust of black basalt as it cooled. The lava moved down the valley of the Skaftá River, advancing as much as nine miles in a single day. When the glowing rock emerged from the confines of the narrow valley four days later, it spread across the flat terrain near the coast. On July 29, the fissure extended another seven miles on the other side of Mount Laki, nearly tearing the dormant volcano in half. Lava spilled from the new break and filled another river valley before activity ceased the following February.

For the Icelanders, the Lakagigar eruption—the largest single outpouring of lava in historic times—was catastrophic. More than 200 square miles were buried beneath three cubic miles of fresh rock, but the lava caused no loss of life as it slowly overran two churches and forty-four farms. The gases released during the eruption, however, had disastrous consequences. That summer and autumn, a thick, bluish haze of sulfur dioxide and other volcanic gases settled over the country, blocking sunlight and stunting grass growth. With insufficient food and fluorine poisoning from the volcanic gases, roughly three-quarters of the country's livestock died, precipitating the Haze Famine, in which 10,000 Icelanders—a quarter of the population—perished. The haze reached eastward to Europe, causing the winter of 1783–84 to be particularly severe. Benjamin Franklin, who was in France at the time, noted the haze and suggested that the fine ash and gases from the Lakagigar eruption had prevented sunlight from warming the continent to its normal temperatures.

Despite its enormity, the Lakagigar eruption was minor compared with the massive outpourings of lava that have flowed from the earth in the geologic past. Half a dozen times during the last 200 million years, molten rock has erupted in such quantities that it left behind flood basalts, extraordinary formations of thick lava flows stacked thousands of feet high. Volcanism on this scale has no modern counterpart; the last episode, which ended about 15 million years ago, left large areas of Washington, Oregon, and Idaho buried beneath the Columbia River flood basalts.

One of the largest of these volcanic episodes occurred 66 million years ago, when molten rock that poured from a rift on the western coast of India covered a third of the peninsula with 500,000 cubic miles of lava. This geologic province is called the Deccan Traps because the hundred or so individual flows exposed by erosion resemble giant steps (*deccan* is from the Sanskrit for "southern," and *trap* is Dutch for "staircase"). Single layers containing a thousand times the volume of rock that erupted from the Lakagigar fissure can be traced across the region. Within half a million years—a blink of the eye in geologic time—molten rock had spread in thick sheets across the landscape until parts of it were buried beneath a mile and a half of new rock.

The tremendous volume of fine dust, carbon dioxide, sulfur dioxide, and other gases that escaped from the earth's interior during these eruptions must have had dramatic effects on the planet's climate. Widespread acid rain and prolonged darkness could have killed vegetation over much of the planet, disrupting food chains. The acidity of the oceans might also have been raised, endangering microscopic organisms. Because the age of the Deccan Traps coincides with the extinction of the dinosaurs and countless other species at the end of the Cretaceous, some scientists believe that the large outpourings of lava contributed to the catastrophe. But the link between the two events has been hard to prove. Others argue that if these extraordinary eruptions of lava had such dire consequences for life on earth, geologists and paleontologists should be able to match other mass extinctions with eruptions of flood basalts. So far, the timing of many of these events is sufficiently uncertain to prevent us from drawing firm conclusions about their simultaneity.

In the early 1970s, J. Tuzo Wilson, a geologist at the University of Toronto and one of the pioneers of plate tectonics, noticed that ancient flood basalts are often associated with the tracks of hot spots, localized regions of current volcanic activity. The challenge for me and my colleagues at the University of Cambridge was to explain how the two features are related and why flood basalts are such rare events. The answers came only after we refined our picture of how processes deep within the mantle shape the earth's surface.

Before we could account for flood basalts, we needed to understand the less spectacular, but continual, bleeding of basalt taking place beneath the sea along the

*A break in the wall of a Hawaiian lava tube offers a glimpse of the torrent of rock flowing within. Such conduits form when basalt cools and hardens on the surface of a lava flow.*
Dorian Weisel

30,000 miles of oceanic rifts that circle the globe. In total volume, this volcanism is more important than the flood basalts, producing almost five cubic miles of new igneous rock each year—enough to build all the oceanic crust, which has been completely renewed during the last 200 million years. On the other hand, compared with flood basalts these submarine eruptions have little effect on the atmosphere because almost all of them occur deep underwater and the individual eruptions are much smaller.

The lava erupting at oceanic rifts originates in the asthenosphere, the ductile mantle that lies sixty miles below the earth's surface. At this depth, tremendous pressures inhibit mantle melting, despite temperatures of more than 2000° F (just as a pressure cooker prevents water from boiling at its normal temperature). Under certain circumstances, however, the mantle rock can move upward toward the surface. Above the ductile mantle, the dozen or so plates of the lithosphere, the earth's rigid outer skin, are in constant motion. At oceanic rifts, where the plates pull apart at rates of a few inches per year, the ductile mantle wells slowly upward to fill the gap. For every ten feet that the mantle rises, the pressure falls by approximately one atmosphere (or about 14.7 pounds per square inch, the pressure that the atmosphere exerts on us at sea level). Halfway up, at a depth of about thirty miles, the pressure falls sufficiently to allow melting to start. Here, a tiny fraction of the mantle rock liquefies. More and more of the mantle melts as it approaches the surface and continues to decompress. By the time the mantle has reached the base of the oceanic crust, about 25 percent of it has melted. The molten rock is very buoyant and percolates rapidly upward until it solidifies near the surface and becomes new crust. Less than a quarter of the magma erupts onto the sea floor as lava.

This simple model of decompression melting of the mantle explains the generation of the entire oceanic crust, which covers more than two-thirds of the globe. In laboratories around the world, researchers have tried to replicate the extremes of temperature and pressure at which mantle

David Jensen

*A prickly pear cactus emerges between columns of basalt in eastern Oregon's Hell's Canyon, left. The hexagonal pattern of the columns formed when a thick lava flow in the Columbia River flood basalts slowly cooled and cracked. The world's major flood basalts are shown on the map below. In many cases they can be linked with hot spots that were once beneath them.*
Joe LeMonnier


rock melts. Their experiments appeared to yield disparate results until Dan McKenzie and Michael J. Bickle, of the University of Cambridge, sifted through the data and plotted melting curves that brought the findings into agreement. They were the first to figure out exactly how much melt would be produced as the ductile mantle welled up under rifts.

Their model not only explains the thickness and composition of oceanic crust but also shows that the amount of melting is extremely sensitive to the temperature of the parent mantle. Measurements of the oceanic crust around the world have shown that its thickness varies remarkably little: it is about four miles thick everywhere. To produce this volume of basalt, the average mantle temperature immediately beneath the lithosphere must be 2440° F, varying by less than 40° F over most of the world.

At the same time that McKenzie and Bickle were formulating their mantle-melting model, Emily M. Klein and Charles H. Langmuir, of the Lamont-Doherty Geological Observatory of Columbia University, were reaching similar conclusions, but from another direction. After analyzing basalts dredged from midocean rifts around the world, they noted that the compositions of these rocks were directly related to the thickness of the crust. Temperature determines not only how much of the mantle will melt as pressure is reduced but also what the magma's chemical composition will be.

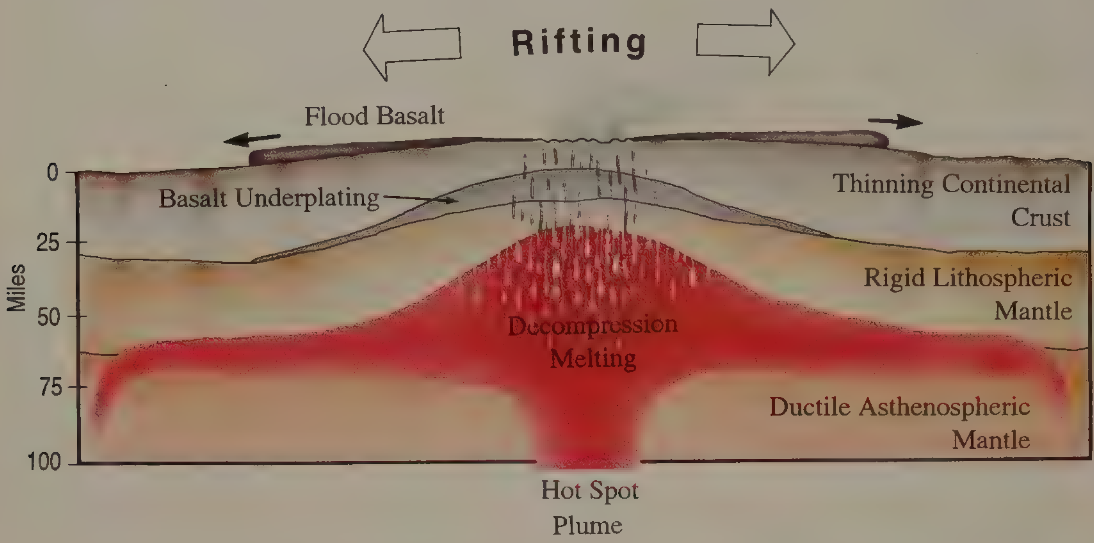
By 1987, we understood the main factors controlling the generation of basalt at midocean rifts, and our attention turned to rifts on the continental plates. Although continental crust is almost five times thicker than oceanic crust, the rigid lithospheric mantle beneath them reaches down to approximately the same depth. Thus, when a continental plate stretches, thins, and finally ruptures, the mantle welling up from below should decompress and partly melt exactly as it does beneath oceanic rifts. If the two halves of a rifted continental plate continue to separate, a new ocean basin forms, leaving continental margins on each side. In many cases, the thin edge of crust drops below sea level, forming a continental shelf. In 1979, a joint French–English expedition used seismic equipment towed behind a ship to obtain a profile of the continental margin west of France beneath the Bay of Biscay. (Seismic waves sent from the surface penetrate deep into the earth and are reflected back by the geologic layers. The resultant seismic images are fuzzy, but essential details of the underlying geology can be discerned.) The survey revealed the expected pattern: the twenty-two-mile-thick European continental crust stretches and thins over a distance of 140 miles until, where it is only four miles thick, it breaks and is succeeded by oceanic crust.

In late 1986, however, another survey farther north in the Atlantic Ocean yielded some very odd results that did not fit this simple picture. Using two British research ships, the *Charles Darwin* and the *Discovery,* we surveyed the continental margin west of the Scottish coast, where the Hatton Bank rises above the surrounding sea floor near the island of Rockall. Graham K. Westbrook, of Birmingham University, England, was the chief scientist on one ship, and I was in charge of the other with a team of scientists from Cambridge. The seismic data analyzed at Cambridge by Susan R. Fowler and George D. Spence showed

Jeff Gnass

*Along the Bruneau River in southwestern Idaho, right, individual lava flows form the horizontal layers typical of flood basalts. The diagram below shows a cross section of the earth where a mantle plume rises beneath a rift. The heat of the plume and the decompression that occurs as rock rises beneath the rift result in both the huge flood basalts on the surface and the underplating of basalt below the crust.*

Joe LeMonnier




that instead of thinning, this section of the continental crust actually thickens as it nears the edge. The thickening is caused by a ten-mile-thick wedge of basalt plated onto the bottom of the continental margin. Because it was clearly different from the overlying crust, we concluded that the wedge was added as a result of the rifting. The only possible source of the new rock was melt added from below. But what could account for its enormous volume?

As we discussed the problem in the tea room of the Bullard Laboratories at Cambridge, Dan McKenzie brought out his first computer plots from the mantle-melting model. When we saw how sensitive the amount of melting was to temperature, we knew we might have the answer to how the wedge beneath Rockall had been formed. An increase of only 180° F (about 7 percent) in the temperature of the mantle would more than double the melt generated by decompression under a rift. A 360° F increase would quadruple the amount of magma rising into the rift. A temperature increase of only 250° F in the mantle would have produced the underplating we had observed. But we knew that mantle temperatures do not normally vary by even small amounts. What was the source of the additional heat?

The question was resolved by a separate line of research that was still fresh in our minds. In 1983 I had led a research team from Cambridge on a cruise to the area around the Cape Verde Islands in the Atlantic Ocean. These islands and others, such as Hawaii, Réunion, and the Azores, dot the world's oceans wherever intense volcanism has built mountains up to four miles high, reaching from the ocean floor to above sea level. In the early 1960s, geologists dubbed them hot spots to distinguish them from the chains of volcanic peaks marking certain plate boundaries. Because of their apparently random distribution, geologists assumed that hot spots were caused by abnormally hot rock welling up from deep within the mantle and had little to do with the vagaries of plate motions.

Using special deep-sea probes driven into the bottom sediments with 2,000-pound weights, we measured the heat being conducted upward through the sea floor. The interior of the earth remains extremely hot from its initial formation and the continuous decay of radioactive elements, even though it has been cooling for billions of years. The heat escapes through the earth's outer skin at a surprisingly high rate: on average, an area equivalent to four football fields continuously pumps out heat at a rate of one kilowatt (about the amount of energy used by a toaster), day after day, year after year, millennium after millennium. In the vicinity of the Cape Verde Islands, however, we found that the heat loss was 25 percent higher than normal and that the elevated heat loss extended over an area stretching 400 miles from the islands.

Two other observations pointed to an exceptionally hot mantle over a broad area. First, the sea floor was pushed up in a gentle, 900-mile-diameter submarine swell more than a mile high at the center, as if the underlying mantle had expanded. Second, satellites measured a gravitational anomaly above the swell, indicating a region of low density in the mantle. Both of these observations are what we would expect to see if the mantle below were hotter than normal.

Robert C. Courtney, then a graduate student at Cambridge, used a computer to model the rising plume of hot rock that would account for our observations around the Cape Verde Islands. In shape, the hot spot resembles a gigantic mushroom, the "cap" being a broad region immediately beneath the sea floor swell and the "stem" a relatively narrow column about 150 miles wide. About 450° F hotter than the surrounding mantle at its center, the column rises until it is deflected

sideways by the rigid lithosphere to form a huge head of bouyant mantle about a thousand miles in diameter. Instead of affecting only a limited area directly above the rising plume, hot spots elevate temperatures over a much broader region of the upper mantle.

Now we knew where the abnormally hot mantle that produced the wedge of basalt beneath Rockall came from—a hot spot. Iceland, which sits directly on top of the mid-Atlantic ridge almost a thousand miles to the northwest of Rockall, owes its existence to a plume that continuously delivers abnormally hot mantle directly under the rift. When the North Atlantic opened up some 57 million years ago, however, the continental margin west of Rockall would have been above the mushroom head of the Icelandic plume. The additional heat beneath the rifting continents would have caused the decompression melting of the mantle at a rate far exceeding that of mantle at normal temperatures and produced a tremendous volume of magma along the rift—enough to emplace basalt beneath the stretching continental crust and erupt flood basalts onto the surface.

We had found the basalt beneath Rockall, and others had discovered a similar underplating of the crust off the coast of Norway, but where were the massive outpourings of lava? In India, the Deccan flood basalts are clearly visible, forming a high plateau, but in the North Atlantic, the continental margins have sunk beneath sea level, hiding their geology. With seismic surveys, however, we could see what was there. Near Rockall, we found lava flows up to several miles thick, extending as far as 100 miles toward Scotland from the edge of the continental crust. Additional seismic profiles revealed massive lava flows along more than a thousand miles of the rifted margins on both sides of the northern Atlantic. From the eastern margin of Greenland to the northwestern margin of Europe, the flood basalts turned up wherever the North Atlantic rift opened above the mushroom head of hot mantle surrounding the Icelandic plume. Until a few years ago, no one suspected massive lava flows there at all, but their total volume is an astonishing half million cubic miles—just as much as in the Deccan flood basalts.

Once we realized that a hot spot beneath rifting continents could explain the massive outpourings of lava along the margin of the northeastern Atlantic, we looked to other flood basalts around the world to see if they supported our model of mantle decompression. Fortunately, a great deal of work had previously been done on flood basalts against which we could test our ideas. In each case we found evidence that flood basalts were associated with continental breakup above a hot spot. For example, the Deccan Traps were formed as the Seychelles fragment (a piece of continental crust now largely submerged beneath the Indian Ocean) split away from mainland India. Since the breakup, the Indian plate has drifted northward, so that the hot spot that was once under the rift is now 3,000 miles south of India, below Réunion. As the plate crept along, the melt generated by the central plume of the hot spot produced a trail of extraordinarily thick oceanic crust, forming the Laccadive-Chagos volcanic ridge and the Mascarene Plateau, features that lead directly from the Deccan Traps in western India to the culprit's present location.

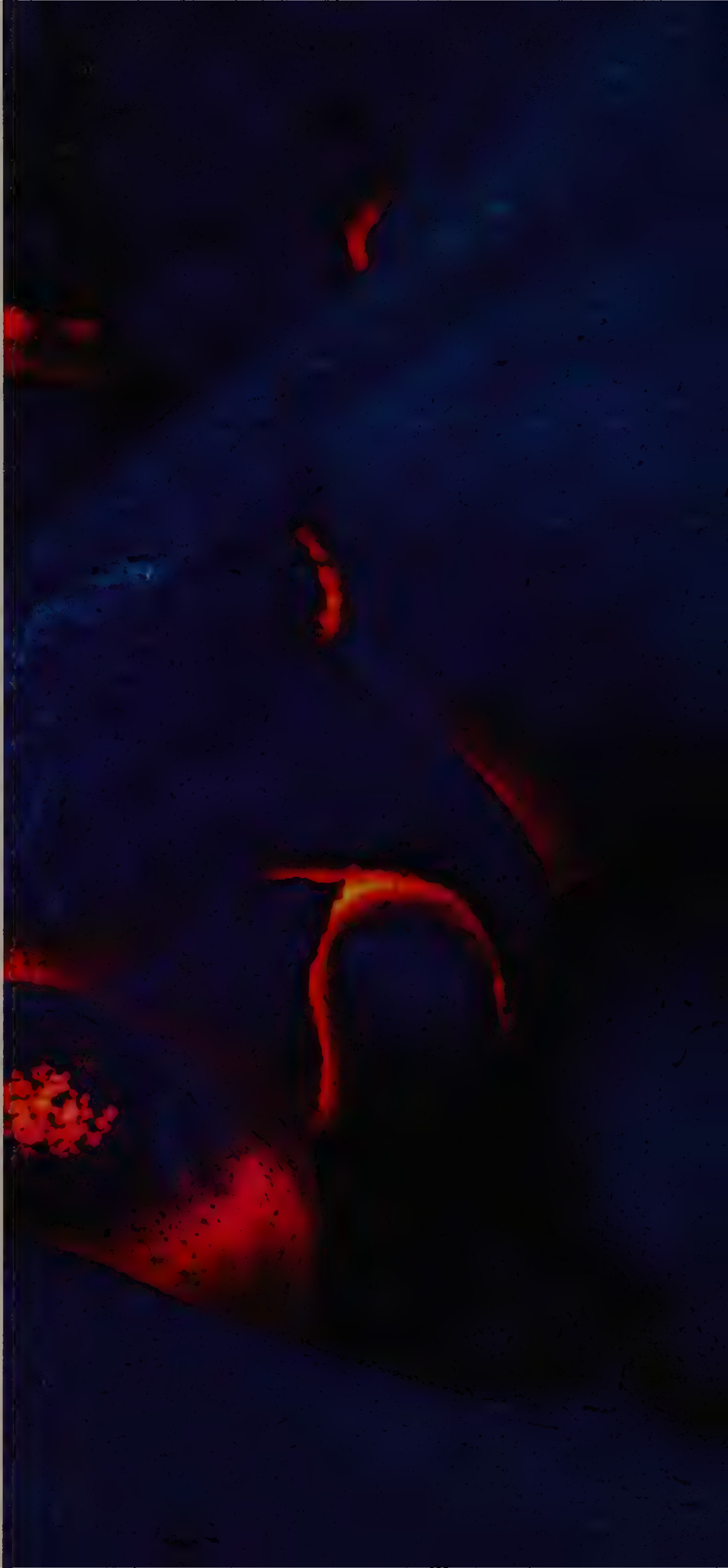
When the African and South American continents split apart about 130 million years ago to form the South Atlantic, two huge flood basalt provinces developed on either side of the rift. Massive melting of the mantle poured up to half a million cubic miles of basalt onto the South American mainland, creating what is now known as the Paraná flood basalt, named after the river that flows across it. Across the ocean, flood basalts of the same age are found in Namibia. As the South At-

*An eruption on Réunion launches thousands of lava bombs into the night sky. The hot spot below Réunion produced the Deccan flood basalts 66 million years ago.*
Krafft/Explorer; Photo Researchers, Inc.

lantic opened between the continents, the hot spot continued to send magma to the surface, leaving thick volcanic features, known as the Rio Grande Rise and the Walvis Ridge, on the sea floor. These two trails lead from the flood basalts to the hot spot lying under the volcanic island of Tristan da Cunha, whose entire population was evacuated in 1962 because of renewed eruptions.

As McKenzie and I refined our model, another puzzling feature of flood basalts began to make sense. Before breaking up, the lithosphere stretches, normally causing the terrain to subside (as it has in the oil-rich sedimentary basin of the North Sea east of Britain). But flood basalts form above sea level; and instead of being confined to narrow valleys, the lava spreads out in sheets extending hundreds of miles away from the main fissure. As at the Cape Verde Islands, a hot spot is capable of uplifting a broad region by as much as a mile. This doming effect, as well as the plating of igneous rock on the base of the stretching crust, counteracts the subsidence normally accompanying rifting. The terrain surrounding a continental rift above a hot spot is actually elevated, so that the basalt simply pours downhill on either side as fast as it erupts. Keith G. Cox, a geologist at Oxford University, noticed that the uplifted continental crust over these hot spots is reflected by odd river-drainage patterns around the world. For instance, in a broad region to the west of São Paulo, Brazil, where the Paraná flood basalts are found, the rivers all flow away from the Atlantic coast. Similarly, the rivers in western India, instead of making their way directly to the nearby sea, flow to the east in a radial pattern away from the coast and Bombay, where the hot spot that produced the Deccan Traps was centered.

Hot spots may also play a large role in breaking up the continents. From the size of the flood basalt provinces around the world, we concluded that most of them were formed as rifts opened above new hot spots. Although hot spots remain more or less fixed in the mantle for millions of years as the plates drift about, they are not permanent. A new plume forms when



*Fingers of highly fluid lava, called pahoehoe, spread outward from a flow on Hawaii. A thin, elastic skin forms rapidly around the molten rock as it cools.*
Jack Jeffrey

rock deep within the mantle grows hotter—and less dense—than the surrounding material and eventually becomes unstable and begins to rise. When a hot spot is born deep within the mantle, an initial, large blob of mantle pushes toward the lithosphere at a relatively rapid rate; then, over millions of years, it continues to be fed by a narrow plume like the one beneath the Cape Verde Islands that we modeled. We estimated that the initial mantle blob that produced the volume of magma found in the flood basalts of the North Atlantic, India, and Brazil must have been at least 100° F hotter than the subsequent, steady flow. The rapid uplift caused by a new plume pressing against an overlying plate may contribute to the stresses causing continental breakup. For example, stretching and rifting of the continental crust occurred between Greenland and northern Europe for tens of millions of years prior to their breakup; but only after the arrival of the Icelandic plume 60 million years ago did rifting proceed far enough for the North Atlantic to begin opening up.

McKenzie and Bickle's simple model of how the mantle melts explains with remarkable success a number of the earth's seemingly unrelated features. The same physical laws that govern the continuous production of oceanic crust covering two-thirds of the globe also dictate where and when eruptions of flood basalts will occur. Although the underlying processes remain constant, their results are often far from uniform. Every now and then, amid the chaos of plate tectonics and the seething mantle below, a rising plume and a continent prone to rifting will coincide, and lava will flood another part of the world. Fortunately, this is infrequent, and during humanity's brief existence we have been spared. The future, however, undoubtedly holds more catastrophic eruptions of flood basalts with long-term consequences far worse than those of Iceland's 1783 eruption. More than two hundred years ago, James Hutton, a Scottish geologist, recognized that human history holds no special place in the vastness of geologic time. He wrote that "we find no vestige of a beginning,—no prospect of an end." □

*Snow blows off the 22,834-foot summit of Cerro Aconcagua, a mountain the prehistoric Inca climbed to offer a human sacrifice.*
Loren McIntyre

# Sacrifices of the High Andes

*Argentine mountain climbers discover a 500-year-old Inca mummy*

by Juan Schobinger

On January 8, 1985, five Argentine climbers were forging a new route to the 22,834-foot summit of Cerro Aconcagua, the highest mountain in the Western Hemisphere, when they stumbled upon a semicircular pile of stones containing a bundled human body, with the top of the skull partly exposed. The discoverers had the good judgment to leave the site intact, taking only photographs and some loose samples of cloth. These later served to identify the site as a pre-Columbian high-mountain sanctuary, a legacy of the far-flung Inca empire, which at its height extended from northern Ecuador to central Chile and Argentina.

On their return, the climbers, members of the Andean Club of Mendoza, reported their find to my colleagues at the Institute of Archeology and Ethnology of the National University of Cuyo. With the club offering to support a return expedition to the site, I was summoned home from vacation to lead an archeological team (some years before I had excavated and studied a similar Inca burial at Cerro El Toro, about 230 miles farther north, on the Chile–Argentina border). Two weeks later I set out with two other members of

*The Aconcagua mummy, the body of a boy about seven years old, below, was colored with a red dye made from the annatto plant. Accompanying it were figurines of men and llamas, right.*
Photographs by Juan Schobinger

the institute and three of the original climbers, who acted as technical guides.

Starting from Puente del Inca (elevation 8,800 feet, on the international highway that crosses into Chile), we hiked through two high valleys, camping at 12,500, 14,700, and 15,400 feet. Our highest camp, at 17,000 feet, was established after crossing a glaciated slope. The final obstacle to our goal was a wall of rock, which we had to scale with ropes. When we reached the site, the elevation according to our altimeter was about 17,400 feet.

The site is on a southwestern ridge of Aconcagua, 2,300 feet below a secondary peak known as the Piramide. Another high wall of rock probably prevented the prehistoric Indians from climbing closer to the top of the Piramide. For two days we explored and mapped the site, which consisted of two broad, semicircular piles of stones, quite collapsed, and a stone circle about three feet in diameter. The semicircle that held the burial bundle was mostly filled with hard permafrost earth, but some had washed away, revealing its contents. Carefully freeing the bundle from the frozen soil, we found it to be the remains of a child, bent in a fetal position with its forehead resting on its knees, like other Andean burials.

The body was wrapped in many pieces of cloth, the outermost of which was layered with yellow feathers, probably of an Amazonian parrot. Long exposure to cold, dry conditions had mummified the flesh. Only the unprotected upper part of the cranium was bare to the bone and partly broken; the dried and shriveled brain could be seen within. From the outside of the bundle we removed a pair of braided fiber sandals and two bags made of the same material. One bag was empty, while the other contained some cooked beans, probably a symbolic meal for the dead child's journey to the Other World.

As the mummy was being packed for the trip down the mountain, we excavated the stone semicircle for other remains. We found six Inca-style statuettes. Three were male human figures: one of gold (formed by hammering and soldering sheet metal), one of solid silver-copper alloy, and one of *Spondylus* shell (a material valued by the Inca that would have been obtained from the seacoast far north, in Ecuador). Averaging about two inches high, all the human figures were clothed, had plume crests, and carried little bags containing fragments of coca leaves. Their faces displayed the characteristic bulge produced by a coca wad placed between the jaw and cheek. Altogether they gave the impression of mountain travelers. The other three statuettes, one of gold and two of *Spondylus* shell, were stylized llamas, colored red on one side and white on the other. These probably were intended as companions to the men, in the traditional Andean way.

After descending the mountain during a heavy storm, we stored the mummy bundle in a freezer for more than a year while an interdisciplinary team was assembled, including some Chilean scientists experienced with mummies and textiles. Together we then carefully opened the bundle. The body, which was in good condition, proved to be that of a boy about seven years old. The skin was coated with red pigment, generally a symbol of life. The boy was wrapped in several blankets made of wool and cotton, two of which were embroidered with geometric and bird designs, and wore an Andean tunic and sandals. A necklace of multicolored stone beads hung around his neck.

The details of the burial identified it as an Inca sacrifice, a practice mentioned in early Spanish chronicles. Inca sacrifices often involved the child of a chief. The sacrificed child was thought of as a deity, insuring a tie between the chief and the Inca emperor, who was considered a descendant of the Sun god. The sacrifice also bestowed an elevated status on the chief's family and descendants.

The Aconcagua mummy represents a major find in a string of high-mountain sanctuaries that are distributed along the Andes from southern Peru to central Chile. It closely resembles another mummy discovered in 1954 on nearby Cerro El Plomo in Chile (*see* page 66). Both sites lie in what was the extreme south of the Inca empire and at similar elevations (the El Plomo site, at 17,700 feet, is the southernmost high sanctuary discovered). Both mummies are boys of nearly the same age, dressed in rich garments. And the accompanying statuettes are of the same style and size (the llamas are practically identical). The two sacrifices may have been performed at the same time, perhaps when the Inca extended their dominion over what is now western Argentina and central Chile, some 500 years ago.

The Inca empire arose in the mid-fifteenth century, when the small Inca kingdom, centered in Cuzco, gained hegemony over its neighbors and began to expand rapidly through military conquest. It was the last and largest of a long series of native cultures and states that arose in the Andes (*see* "Long Before the Inca," by Richard L. Burger, February 1989). Known as Tawantinsuyu, Land of the Four Quarters, the empire was defined by a network of paths and highways that pro-

*A network of paths and highways connected the Inca capital, Cuzco, to the empire's four* suyus, *or "quarters." In the two southern* suyus, *archeologists have identified more than one hundred Inca ceremonial sites located on high mountains. Those mentioned in the text are shown here, along with Esmeralda, a low-mountain burial.*
Joe LeMonnier


vided an official link between the capital and the imperial provinces.

The rise of the Quechua-speaking Inca rested not only on their military might and the ability of their rulers but also on their imposition of a highly organized economic and political system on a diversity of ethnic groups, who were permitted to retain many of their customs and often their own leaders. Fierce opposition from groups in northern Ecuador and central Chile, however, slowed the Inca expansion before the arrival of the Spaniards, whose conquest in the 1530s marked the end—or transformation—of the empire.

Including Aconcagua, El Plomo, El Toro, and several other confirmed burials, at least 115 archeological sites located high in the mountains (15,000 feet or more) appear to be Inca ceremonial or symbolic sites. They range from simple stone rectangles and isolated artifacts to complex sanctuaries for offerings and burials, such as on Aconcagua. The highest, on Llullaillaco on the Chile–Argentina border and Mercedario in Argentina, are located at about 22,000 feet, remarkable considering that pre-Columbian people lacked sophisticated climbing equipment. The Inca not only reached these heights but in many cases also carried up firewood and other objects and erected structures using stones brought from lower parts of the mountains.

In general, high sanctuaries are situated on a mountain's summit or on a plateau near it. But cases like the Aconcagua burial, almost 2,300 feet below the mountain's secondary peak, show that other favorable locations could be chosen. In addition, sanctuaries have been found atop lower mountains, the most remarkable being one on Cerro Esmeralda, near the city of Iquique in northern Chile. Some years ago, just 3,000 feet above sea level, a construction crew found a site very similar to those of the high Andes, containing the bodies of a girl and a young woman and numerous Inca-style grave goods.

The high-mountain sites are spread over more than 1,200 miles, from Coropuna in Peru to El Plomo in Chile. They are located exclusively in the region of the two southernmost *suyus*, or "quarters," of

the Inca empire, and especially in Qolla Suyu (named for a prominent indigenous group). Some suggest that this distribution reflects better chances of preservation on the southern peaks or is a result of their more thorough exploration, but I don't think this is the explanation. Instead, I believe that in establishing these sanctuaries in the south, the Inca, whose own religion emphasized sun worship, were responding to the veneration of high mountains by local peoples.

For thousands of years before the Inca empire, groups lived in and crossed high Andean regions, including the high, grassy plain (*puna*) that runs from southern Peru to central Bolivia and the high desert plateau that continues into northern Chile and western Argentina. People in many societies venerate mountains as sacred places, centers of spiritual power, or seats of deities. Accordingly, mountains, especially volcanoes (which are fairly common in the southern Andes, although usually extinct), were probably venerated before the Inca expansion, principally in the high-plateau region, the heart of what the Inca called Qolla Suyu. Anthropologist Johan Reinhard has documented the survival in the Andes of beliefs and ceremonies in which mountains, as sources of water, are invoked as givers of life and fertility.

I believe that in their southern expansion, the Inca encountered people who venerated mountains and occasionally climbed them for ritual purposes, and that the Inca then elaborated these customs and integrated them into their imperial sun worship. What had been essentially a folk practice was transformed into a politically significant ceremony. In contrast, in the northern parts of the empire, even though a volcanic region exists in present-day Ecuador, there seem to be no high-mountain sanctuaries. Perhaps this is because that region lacked a cultural precursor, and the Inca wisely did not attempt to import a practice that did not fit local manners and cults.

But the extension of high-mountain sanctuaries (such as the Aconcagua site) to the southernmost extreme of the Inca empire requires some further explanation.

# Another Mummy

## by Thomas Besom

Three decades before the mummy of a young boy was unearthed on Aconcagua, a similar discovery was made near the 17,815-foot summit of Chile's Cerro El Plomo. Acquired by Chile's National Museum of Natural History in Santiago, the El Plomo mummy was scrutinized by numerous specialists, including medical doctors. Luis Prunes, professor of dermatology at the University of Chile, observed that most of the fingers on the left hand were white, a sign of frostbite, indicating that the child was alive when taken up to the frigid mountain heights. The feet and ankles were swollen, suggesting that shortly before death he traveled over rough terrain. Rodolfo Merello of the Luis Mackenna Hospital, who X-rayed the body, estimated the boy's age as eight or nine. Professor of forensic medicine Jaime Vidal and his assistants examined a small sample of the flesh and determined that the outer layers of skin were dehydrated by the cold, dry air, while the deeper layers were partially preserved through saponification, a chemical change of fats into a soapy substance.

Grete Mostny, head of the anthropology section of the National Museum of Natural History, and others investigated the mummy's clothing, adornments, and accompanying artifacts. The boy's face was painted red, with four yellow lines on each side radiating from his nose and upper lip to his cheeks (the pigments were iron oxide and arsenic sulfide mixed with animal fat). His long, black hair was oiled and plaited into more than 200 tiny braids. On his head he wore a band made of human hair and a headdress of black llama hair decorated with condor feathers.

The boy wore a silver pendant in the shape of a sideways H beneath his chin (here shown on his forehead) and a wide, silver bracelet on his right forearm. His body was clothed in a sleeveless tunic of llama wool cloth, an alpaca wool cloak, and llama hide moccasins. Interred with him were two bags, one of which

Loren McIntyre

was full of coca leaves. Also accompanying him were five little pouches containing matted human hair, baby teeth, fingernail clippings, and bits of red thread. The human detritus apparently belonged to the boy and, as was the custom, was saved by his family for his eventual burial, so that his spirit would not have to search for it.

Three figurines were found with the mummy, including two llamas, one of a hammered and soldered alloy of gold, silver, and copper, and a smaller one of *Spondylus* shell. The third figure, a hollow silver female idol, was dressed in miniature clothes, including a cap with parrot feathers attached.

Fragments of decorated pottery found on El Plomo near an Inca structure a little way down from the burial site were studied by Chilean archeologist Gonzalo Figueroa, who found them to be of late Inca style. Several Spanish chronicles state that before the Inca sacrificed a victim, he was given corn beer as an intoxicant. This beer was often transported in a vessel that had a pointed base, two handles, and a long neck; a fragment of such a vessel was found on El Plomo. The most recent study of the mummy was conducted in July 1982 by Patrick Horne, a paleopathologist, who examined a sample drawn from the boy's liver for a residue that would indicate the presence of alcohol. The results were inconclusive; he did, however, find traces of vomit on the tunic, which might mean the child threw up after taking a couple of drafts of beer at high altitude. Supporting the hypothesis that the boy was intoxicated before he was sealed in his grave is his completely peaceful countenance; apparently he passed directly from his deep stupor to death resulting from exposure.

As evident from the clothing and accompanying objects, the boy was a subject of the Inca empire. The pendant, bracelet, moccasins, and long hair suggest he was from Qolla Suyu, the empire's southeastern quarter. According to Mostny, his braided hair suggests that he may have been a member of a group living near Lake Titicaca, such as the Lupaca. Probably he was the son of a lower-class noble, perhaps offered to the Sun god to perpetuate the sun's power and to insure the good health of the emperor, who was considered a direct descendant of the god. Or he may have been an offering to El Plomo, which as a source of water was probably regarded as an important local deity.

*Thomas Besom is pursuing a doctorate in archeology and anthropology at the State University of New York at Binghamton. He first became interested in the Inca empire and high-altitude sanctuaries while living in Chile, where he climbed El Plomo.*

*Llamas graze on the high plain, or* puna, *in southern Peru, near Lake Titicaca.*
Claus C. Meyer; Cámara Três Fotografia

This region was inhabited by valley settlers who rarely made ascents of high peaks. Furthermore, the Araucanians, who resisted Inca expansion still farther southward (and continued afterward to resist European domination) lacked high-mountain sanctuaries, although they did venerate volcanoes. Thus, the climbing of mountains for ritual purposes may not have been indigenous to this region.

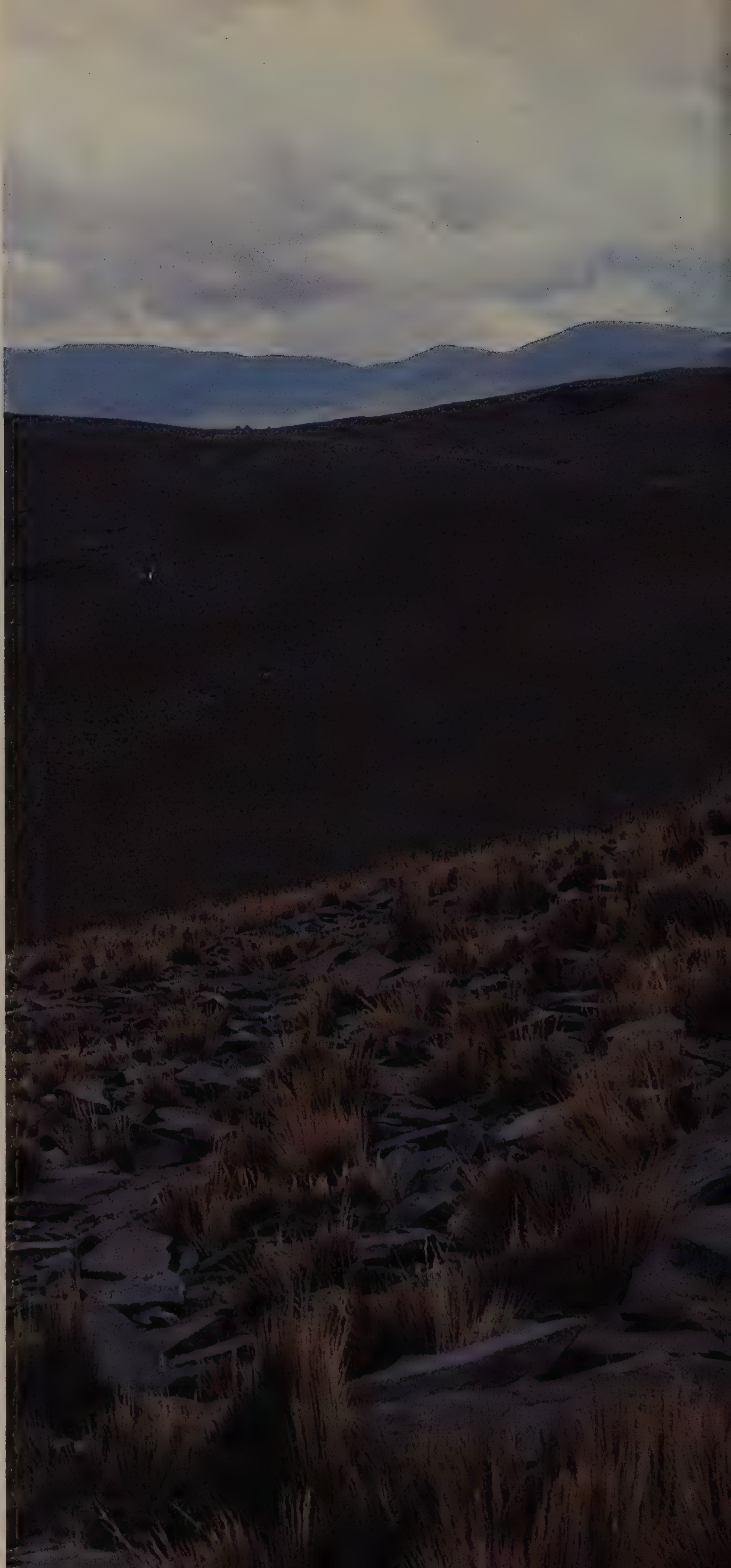
Of all the high-altitude sanctuaries, those in the extreme south—especially the ones with burials—are richer and more purely Incan in their artifacts. They are also situated at more inaccessible and inhospitable sites than those of the *puna* and high plateau. From a religious standpoint, these mountains were new territory. I suggest that the Inca were acting more independently in establishing sanctuaries so far south. Perhaps they wanted to contribute in this way to the political and cultural unification of Qolla Suyu.

The southern expansion of the empire brought with it a new social, economic, and religious order that scholars sometimes call Pax Incaica. The Inca royalty probably took possession of the new region as if it were a gift bestowed by the Sun god. The high sanctuaries, particularly those crowned with human sacrifices, may have been erected as visible signs both of the new order and of the presence of the imperial god. Apparently, the Inca reasoned that to fulfill his protecting, ordering, and fertilizing functions, the Sun god required valuable offerings in the highest places humans could reach.

We do not know if human sacrifice was part of non-Inca culture in this region, but based on the Spanish chronicles, as well as archeological evidence, most scholars agree it was part of Inca culture. The practice marked certain occasions, including epidemics, earthquakes, solar eclipses, and annual festivals. Human sacrifices were also performed on the death of an emperor, in order to provide an escort for him on his journey to the Other World and to bring good luck to his successor.

Along with El Plomo and the burial of a young woman on Pichu Pichu (a mountain west of Lake Titicaca), Aconcagua now brings to three the number of cases in which statuettes have been found in association with high-altitude human sacrifices. At least a dozen more sites are known where figures of humans and llamas appear without sacrifices (sometimes in lower sites in different parts of the Inca realm). A number of years ago I speculated that in some cases, and generally for the later Inca period, such figures were offered in place of real sacrifices, a substitution known in other cultures. But now that we know of three cases where both occur, this interpretation needs to be changed or at least supplemented.

Statuettes may have been used for several different symbolic purposes. In the



*Heading south through Argentina, a main Inca road passes along the eastern side of the Andes mountain range.*
John Hyslop

case of Aconcagua and the other two burials, we may interpret them as travelers intended to escort the sacrificed person on his or her journey to the Other World. In two of these examples, the human statuettes were female (symbolizing perhaps the Earth Mother, Pacha Mama)—in one case accompanying a female (Pichu Pichu) and in the other case a male (El Plomo). At Aconcagua, instead, the statuettes were male, accompanying a male. The significance of these differences is not known.

In the case of high-mountain burials, the occasion for human sacrifice was the expansion of the Inca empire, perhaps coinciding with the inauguration of a section of the Inca road network, with its associated way stations. This network comprised important north–south routes along the eastern and western sides of the Andes and various transverse (roughly east–west) routes. The high sanctuaries, particularly those with burials, are generally associated with transverse routes, where a path connected eastern and western slopes or ran from one mountain range to a parallel one. Near such routes, the Inca chose a high peak as a sacred mountain. It was then climbed, a sanctuary was built, and offerings were buried, including, in some cases, the most valuable: an innocent human life. The Aconcagua sanctuary, for example, was close to a major transverse route, essentially the same one followed today by the international highway between Argentina and central Chile.

The Inca may have attached special significance to the transverse roads because in their general orientation they resembled the path followed by the sun. The high passes through which the traveler crossed from one slope to another may have been likened to the door that separates this world from the one beyond, the divine world (even today, people crossing some of these passes leave offerings—stones and other objects—which over time have accumulated into huge piles). As part of the array of rugged, high-mountain sites, Aconcagua provides archeologists with valuable clues concerning the sentiments, as well as the practices, of prehistoric Andean peoples. □

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# Cape Breton Highlands, Nova Scotia

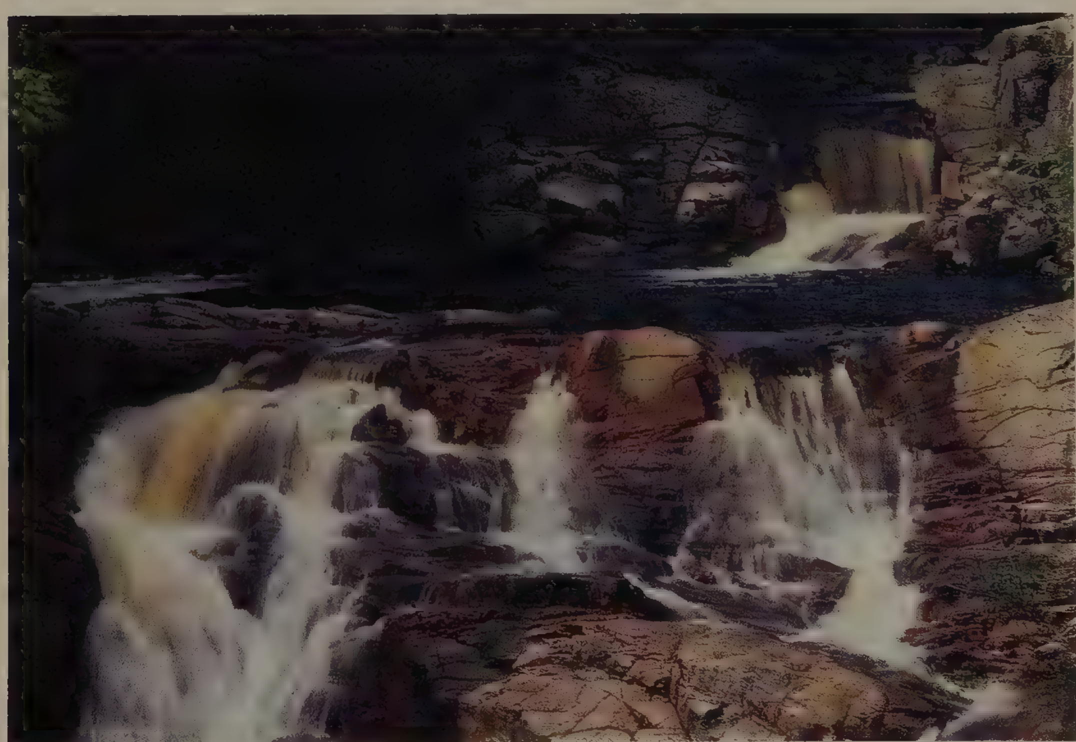
by Robert H. Mohlenbrock

Travelers to the northern reaches of Nova Scotia's Cape Breton Island have long admired its densely forested canyons, the rock cliffs that drop precipitously to the Gulf of Saint Lawrence, and the rugged shorelines that face the pounding Atlantic Ocean. Canada has set aside 367 square miles of this landscape as Cape Breton Highlands National Park. The park encompasses a large plateau, ranging from 1,000 feet high at its margins to 1,700 feet at its center, through which clear rivers and streams have carved deep valleys. Picturesque waterfalls plunge into some of the canyons following heavy rainfall. The park also boasts many plants and animals that are near the limit of their geographical ranges.

Because glaciers completely covered the region during the Ice Age, all the vegetation present today became established sometime after the ice retreated, 12,000 years ago. Sixty-four species are rare in this part of the country, mostly arctic-alpine plants that were driven south during glaciation and subsequently found favorable niches on Cape Breton, usually in out-of-the-way places where competition from other species remained minimal.

Botanists recognize three major life zones within the park, which generally correspond to three North American forest types: taiga, boreal, and acadian. The taiga, which covers about 22 percent of the park's land surface, occupies the highest elevations at the center of the plateau. Surrounding the taiga is the boreal forest, which accounts for 55 percent of the land. The rest is acadian forest, which grows on the gentle slopes near the Atlantic Ocean and extends into the canyons.

Transitional between boreal forest and the treeless arctic plain known as tundra, the taiga forest consists of stunted evergreen trees. These trees, mostly black spruce and balsam fir, may be only three feet tall after 150 years of growth. They owe their dwarfed condition to a harsh environment—extreme cold, exposure to ice, a short growing season, and poor soils. Numerous gray lichens, such as reindeer lichen, cover much of the ground, crunching beneath every footstep. Elsewhere, soils made acidic by the accumulation of peat moss provide ideal conditions for wild blueberry, Labrador tea, and trailing arbutus. Poorly drained depressions harbor species rare for the area, mostly members



James Hanken; Bruce Coleman, Inc.

*The coast of Cape Breton Island, left, is washed by the Atlantic Ocean near Black Brook. Above: Mary Anne Falls*

Joe LeMonnier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of a more arctic flora. They include cloudberry, the arctic bur reed, and four miniature species of birch.

Boreal forest—here a southern arm of vegetation widespread to the north—generally cloaks the western slopes of the highlands and the upper slopes of the canyons. Spruce and balsam fir dominate, with paper birch a characteristic deciduous tree. The understory is lush and varied. Among the unusual plants are oblong-leaved rattlesnake plantain orchid and a ground pine.

Most majestic is the acadian forest, which here consists of huge sugar maples (among the northernmost of this species in the wild) and other deciduous trees, with smaller numbers of eastern white pine, eastern hemlock, and balsam fir. These trees line the lower slopes and valley bottoms, with their streams and rivers.

There are several places to observe the acadian forest, including the areas adjacent to the North Aspy River, the Mackenzie River, and Corney Brook. One of my favorites is a short trail along McIntosh Brook, whose waters rush through a second-growth forest of white spruce, yellow birch, sugar maple, and red maple. Because the trees grow close together and form a dense canopy, the forest floor is covered by low-growing mosses and such shade-loving wildflowers as the round-leaved orchid, bluebead lily, two-eyed berry, and zigzag goldenrod. Often found at the edge of the brook are colonies of horsetail, a plant with jointed stems whose leaves are nothing more than tiny, triangular, blackish scales.

A more extensive trail system penetrates the beautiful Grande Anse River gorge, just east of McIntosh Brook and accessible from the Lone Sheiling parking lot. Large, mature sugar maples (one of them 120 feet tall) and yellow birches are very common on the steep side slopes, while American beech prevails in broader portions of the valley floor. One huge American elm is about 250 years old.

Because it contains many plants rare for the region, the Grande Anse River gorge has been named an International Biological Preserve. Beneath the old-growth sugar maples and yellow birches, botanists have recorded twenty-one species of ferns, from the very large ostrich fern, interrupted fern, and cinnamon fern to the smaller and more delicate oak fern, beech fern, and fragile fern. Among them is green spleenwort, which is normally found in more southern regions. Farther up the Grande Anse, where the valley narrows, other plants grow on the wet, rocky cliff faces, including roseroot sedum and smooth woodsia fern. The rock vole and Gaspé shrew, mammals that are very rare for Nova Scotia, also reside here.

*This month, columnist Robert H. Mohlenbrock takes a break from his usual beat—the 156 U. S. national forests—to introduce a neighboring territory. Mohlenbrock is Visiting Distinguished Professor of Plant Biology at Southern Illinois University at Carbondale.*

Jeffrey Blaufarb

*Mist hangs over the shallow Lake of Islands, above. Steep rock cliffs, opposite page, face the Gulf of Saint Lawrence at Red River, just north of the national park.*

John E. Swedberg: Bruce Coleman, Inc.

# Observatory Hill

by Thomas D. Nicholson

Visitors to Washington, D.C., this spring and summer should take a tour of the U. S. Naval Observatory on Massachusetts Avenue, one of the most accessible observatories in the country. Established in the mid-1800s, it is also the oldest large observatory in the country. Although its original purpose was to serve the needs of sailors by establishing time standards and providing precise charts for celestial navigation, the facility has made significant contributions to astronomy.

The observatory's main telescope dates back to 1873. Its mechanical parts have been modernized, but its high-quality twenty-six-inch lens is the original. Through this lens (the largest of any refracting telescope of its time) Asaph Hall discovered the two moons of Mars in August 1877. After World War II, with increasing deterioration of Washington's skies because of light and air pollution, the Naval Observatory established a station under the clear skies of Flagstaff, Arizona. Today, a sixty-one-inch reflecting telescope at the newer facility, together with the one in Washington, is devoted to the precise measurement of stellar positions and distances.

Before visiting the observatory, obtain a copy of *The House on Observatory Hill,* by Gail S. Cleere (available from the U. S. Government Printing Office, Washington, D.C. 20407). The paperback is a guide to the history and facilities of the observatory, as well as to many of Washington's classical mansions. The guide also describes the vice president's official residence—the House on Observatory Hill. Gerald Ford was the first vice president scheduled to live there, but before he could move in, he became president. Prior to Ford, we had no official residence for our vice presidents.

Events in the calendar below are given in local time unless otherwise indicated.

April 1: Four of the five bright planets are evening "stars": Brilliant Venus, dominating the show, is in the west in the early evening; from dusk until after midnight, Mars is in the west, below Gemini's bright stars Pollux and Castor; brilliant Jupiter is in the south and west until it sets well after midnight; and until the 14th, Mercury is low in the southwest in early twilight.

April 2: The waning gibbous moon, three days past full, rises after 10:00 P.M. and fills the southeast with moonglow; to its left is Scorpius' bright star Antares.

April 3: The moon occults bright red Antares over Europe, but the event ends before the moon rises in America, shortly after 11:00 P.M.

April 4: Mercury starts the westerly loop in its apparent orbital path, which hastens its departure from the evening sky by midmonth.

April 5–6: Apogee moon (farthest from the earth) is in the Archer's "teapot" during morning hours; on the 6th the moon is just left of the teapot's uppermost star.

April 7: Moonrise is at about 1:30 A.M., and last-quarter phase is at 1:35 A.M., EST. Set clocks ahead one hour; daylight saving time begins at 2:00 A.M. on the 8th.

April 8: Saturn and the waning crescent moon to its right can be seen in Capricornus from about 4:00 A.M., EDT, until sunrise. The dim stars of the Sea Goat form the shape of a bikini around the moon and Saturn.

April 9–12: Each morning, the predawn crescent moon rises slimmer and later while moving slowly away from nearby Saturn. The thirtieth anniversary of manned space flight (Yuri Gagarin) is on the 12th.

April 14: New moon is at 3:38 P.M., EDT. Mercury is at inferior conjunction, passing between the earth and the sun and entering the morning sky.

April 15–16: The very thin new crescent moon may be visible in twilight on the 15th, but certainly by the 16th. The three planets aligned above the moon in the evening—Venus, Mars, and Jupiter—lie approximately along the path the moon will follow on the nights ahead.

April 17: Perigee moon (nearest the earth) is at about 1:00 P.M., EDT. The moon is just above Venus after passing it before sunset. Aldebaran is the reddish star to the left in Taurus. Dimmer Mars and bright Jupiter are above the moon and Venus.

April 19: The thick crescent moon and Mars appear very close together tonight. The moon drifts slowly left past Mars as the night progresses.

April 21: First-quarter moon is at 8:39 A.M., EDT. The moon, to the left of brilliant Jupiter, moves away from the planet. Gemini's twin stars, Pollux and Castor, are virtually in line with Jupiter and the moon. Venus moves through the stars of Taurus, passing above Aldebaran.

April 22–23: With the maximum of the Lyrid meteor shower at about 1:00 P.M., EDT, on the 22d, meteors radiating from the constellation Lyra may be visible both mornings. The hourly count is only about fifteen, but the sky is moonless.

April 25: Mars forms a narrow inverted isosceles triangle with Pollux and Castor in the darkening western sky.

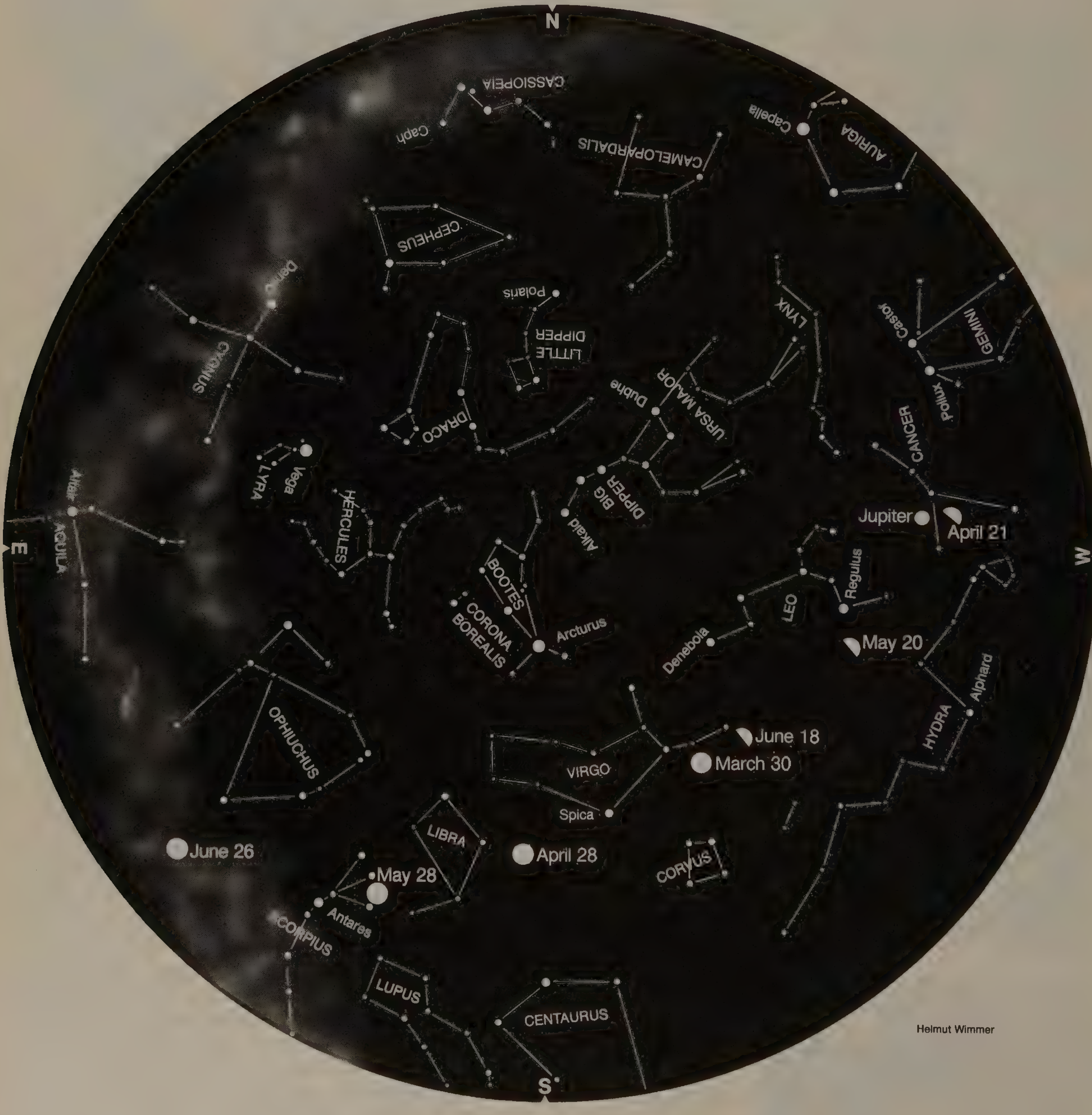
April 27: Virgo's bright star Spica is just above the moon, which is not quite full, as they rise in the southeast after sunset. Mercury ends its retrograde (westerly) motion.

April 28: Full moon is at 4:58 P.M., EDT, shortly before it moves into Libra.

April 30: The moon is again close to Scorpius' Antares, the reddish star to its left. The fainter stars of the Scorpion's hooked tail curve downward to the left, ending at Shaula, about where its stinger would be.

The spring Sky Map shows the sky for April, May, and June from 40° north latitude at the hours given below. To use the map, hold it vertically in front of you with south (S) at the bottom and match the lower half with the stars you see when you face south. As you face in other directions, turn the map to bring the corresponding compass direction to the bottom. The stars move continuously westward during the night. By morning (before dawn), those on the western half of the map will have set, those on the eastern half will have moved into the west, and new stars (those of the summer evenings) will have risen in the east. The map shows the sky at about 2:30 A.M. on April 1; 1:30 A.M. on April 15; 12:30 A.M. on May 1; 11:30 P.M. on May 15; 10:30 P.M. on June 1; 9:30 P.M. on June 15; and 8:30 P.M. on July 1. The map can be used for an hour or more before and after the times given.

*Thomas D. Nicholson is director emeritus of the American Museum.*




Helmut Wimmer

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# A Continent on Fire

by Jon E. Keeley

When Yellowstone National Park ignited several summers ago, some land managers considered this to be the "*Challenger* accident" of fire ecology. The bureaucratic backlash did temporarily halt the use of fire on U. S. federal lands, but in the end this event did much to publicize the role of fire in natural ecosystems. In the same manner, Stephen J. Pyne's book *Burning Bush: A Fire History of Australia* will do much to educate the global community about the role fire has played in the lives of Australians, as well as citizens of other continents.

Stephen Pyne is a great storyteller, and here he weaves as fine a tale as one could imagine about a phenomenon as seemingly ordinary as fire. The history of fire is related through a collection of four "books": *The Eucalypt, The Aborigine, The European,* and *The New Australian.*

The story begins hundreds of millions of years ago, at a time when the present continent of Australia was but a piece of a larger landmass known as Gondwana. Through eons of time, Australia split off

BURNING BUSH: A FIRE HISTORY OF AUSTRALIA, by Stephen J. Pyne. *Henry Holt and Company, $27.95; 497 pp., illus.*

from its Gondwana siblings, Africa, India, and Antarctica. This breakup isolated Australia, allowing its biota to follow a separate course of evolution. The purpose of Pyne's story is to convince the reader that fire, more than any other force, has been an overriding feature of the Australian landscape. Rich in words and images, the author's message is that "fire enhances, multiplies, stimulates, recycles, and animates, a plural not a singular process, massaging a varied, subtle biota."

In Australia, the eucalypt carries the message of fire from its earliest origins to the present. It is so flammable that "once torched, the burning bush resembled a spiral nebula, its fuels and fires like paired arms locked into an accelerating vortex." In the process of adapting to a life with fire, the eucalypt grew so accustomed to this feature of nature that life without it is impossible for some *Eucalyptus* species. In effect, the eucalypt has become the element of combustion on which Australian fire depends.

Stephen Pyne is the Zen master ecologist who teaches us that separating the organic and inorganic is not always possible. Like the Zen idea that an organism's skin does not separate it from, but rather joins it to, the environment, Pyne tells us that fire and plant are one, and "the linkage between life and fire is the biomass they share—for one, part of a cycle of nutrients and habitats; for the other, fuel."

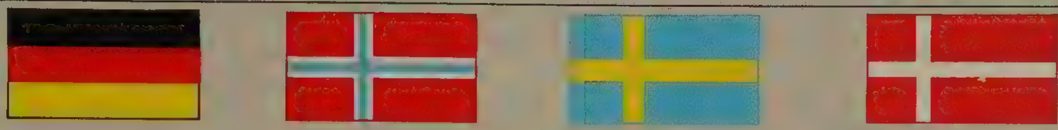
*Burning Bush* gives the reader a glimpse into the world of plant adaptations to fire, introduced as "unimaginable freaks of fire." Here are described plant structures such as the lignotuber, a woody, underground, swollen stem that stores nu-

*Farmers fighting a bush fire that threatens their bark house*

From *Cassell's Picturesque Australia* (1980), edited by E.E. Miller

American Museum of Natural History

# SCANDINAVIAN SAGA



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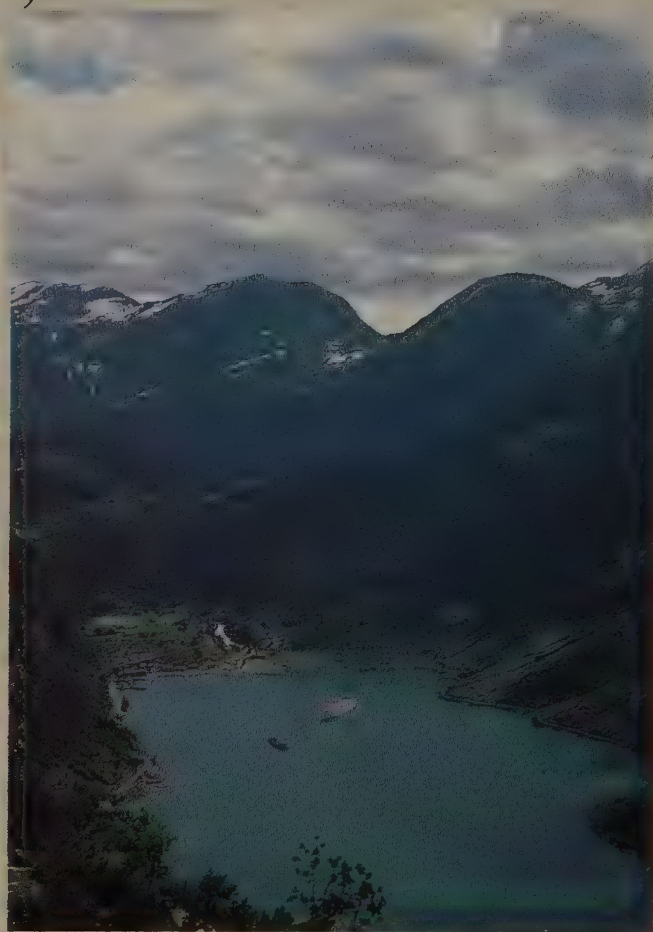

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trients and water. The lignotuber also houses numerous dormant buds ready to spring to life once the aboveground stems are destroyed. Other plant species hold their seeds inside woody cones for many years, and dispersal to germination sites occurs only after fire. Thus, the critical seedling stage of the plant's life history is given the advantage of fire's beneficial effect; plant competitors are removed and the combustion of organic matter releases valuable nutrients. Other pyrogenic "freaks" include the grass tree *Xanthorrhoea,* a plant that seldom if ever flowers, except following fire.

The ecology of Australian plant adaptations to fire is a fascinating study that has already generated many research papers. One disappointment in the *Burning Bush* was that little more than what I have outlined above found its way into this book. Considering the depth and detail Pyne has given to the sociological aspects of fire, this plant ecologist felt cheated. And curiously, as a scientist I did not find, as Stephen Pyne worried in the preface, that his "poetic license" set my "teeth on edge." In fact, quite the opposite, the paucity of rich metaphor and poetic license in the second half of the book was noticed and missed. In the very few instances my teeth were on edge I felt this feeling would be shared with nonscientists; for example, "The mulga melange hosts a biotic corroboree, a massing of multiple species that dance around a central fire which illuminates but does not inform." Such phrases dance around the point, illuminate the prose, but fail to inform.

The power behind Stephen Pyne's message, however, is that it goes beyond describing the history of fire in Australia. Here we have a glimpse into the life of the Aborigines and how fire was integrated into all facets of their existence. This book will open a new world for many readers who previously never considered how fire could be incorporated into the psyche of a race of people. Where the eucalypt is described as a pyrophyte, the Aborigine is profiled as a pyrophile. "In the Aborigine, Australian fire had discovered an extraordinary ally."

What developed was a symbiosis between humans and nature. Until approximately 40,000 years ago, lightning was the primary source of ignition for wildfires on the Australian continent. Upon the arrival of *Homo sapiens,* fire expanded its geographical and seasonal range. However, not only did the Aborigines carry the torch farther into the bush and beyond the seasonal limits of lightning but they also used fire to extract many of their resources from the world around them.

From the age of three the Aborigine was educated in the ways of utilizing fire. Fire was more than a cooking tool. It was an agricultural tool, used to manage the natural ecosystems, encouraging some food plants and discouraging other, useless plants. Fire was a hunting tool, used to drive kangaroos from hiding. Fire also was a means of protection, capable of driving off enemies, as well as reducing combustible plant materials, which if allowed to accumulate were capable of sustaining catastrophic fires.

In the chapter "Fires of the Dreaming," Pyne describes how "fire was as integral to the mental as to the material existence of the Aborigine." It formed the basis of their spiritual world. The reader is led to believe that without fire much of what makes all of us human would not have been possible. Campfires allowed us to extend the length of our waking hours into the night. Such time is less useful for hunting and basic survival than for intellectual intercourse; for storytelling. It is around the campfire that the Aborigines created their spiritual universe. "Spiritual invention depended on a material context of heat and light; the social life that sustained cognition pivoted around a fire." Much Aboriginal myth and ritual involved fire, and Pyne recounts numerous Aboriginal tales involving its use.

Europeans entered the scene and set about a course of altering the ecology of fire on the Australian continent. However, such changes came about not because the new inhabitants were unfamiliar with fire; "probably no fire practice in Australia—or throughout all of Gondwana—lacked an antecedent in British history." As with the Aborigines, fire was an integral part of the British cognition, and Britons had "fire rites, fire ceremonies, and fire myths." What complicated the role of fire in the life of the European in Australia was the multiplicity of roles played by the new settlers. For example, in order to burn the cover from certain rock formations, miners "brought fire where fire had been at best an infrequent presence." Pastoralism brought new fauna with "a fever that ravaged every niche in Australia," and "by ruthless overgrazing, the alien herds devoured the fine fuels that could carry fire." What followed was a disruption in the local ecological infrastructure; unpalatable shrub species, previously held at bay by fire, were now allowed to proliferate and shade out the forage grasses. As a consequence, more combustible plants accumulated, setting the stage for catastrophic fires, and Australians have lived through many.

Beginning in the midnineteenth century, major catastrophic conflagrations, named after days of the week, Black Tuesday, Black Sunday, and so on, devastated various inhabited parts of Australia. Each seemed to bring with it a different message and to provoke a different response from the populace. Using these events, Pyne leads the reader in detail (perhaps too much detail) through the historical development of the modern-day Australian fire strategy.

The "New Australian" is the product of centuries of cultural evolution on the Australian continent. As the populace strove for its own identity in the world, fire was part of the baggage. People in the field of forestry in various countries of the world have developed policies of dealing with fire; from this body of knowledge, and much personal experience, Australians have fashioned their own strategy for living with fire in the natural environment.

*Jon E. Keeley is a professor in the Department of Biology at Occidental College, Los Angeles. A plant ecologist, Keeley specializes in the fire ecology of Mediterranean climate ecosystems.*

# At the American Museum

Tropical Rain Forests

In conjunction with the exhibition "Tropical Rainforests: A Disappearing Treasure," now in Gallery 3, a variety of special programs will highlight the complex dynamics and the destruction of these tropical resources. Writer Alexander Shoumatoff and Pulitzer Prize-winning poet W. S. Merwin will be the featured speakers on Wednesday, April 17, at 7:00 P.M. in the Main Auditorium. Shoumatoff has written about the politics of the Amazon rain forest and the region's rubber tappers, who have come to symbolize the struggle to save the fragile ecosystem. Merwin will speak about Wao Kele O Puna, the largest intact lowland rain forest remaining in Hawaii.

In a two-day workshop on Friday and Saturday, April 19 and 20, in the Kaufmann and Linder theaters, seven speakers will address such issues as the use of media and education in rain forest conservation, the pharmaceutical value of tropical plants, the importance of healthy river systems for the survival of tropical forests and the people living in those regions, and developments in the field of tropical agroforestry. Admission is $15 for one day; $25 for two days. In celebration of Earth Day, Sunday, April 21, five films that look at tropical deforestation and its impact on plant and animal species will be shown. For details about these and other programs, call (212) 769-5305.

*Artist Mark Gostnell finishing the mural in the Museum's "Tropical Rainforests" exhibition.*
Denis Finnin; AMNH

Wildscreen '90

Nine new works by the world's best wildlife filmmakers will be presented in a special screening on Sunday, April 28, in the Kaufmann Theater. The subjects include the Al Murrah Bedouins of southern Arabia; fierce crocodiles of the Grummetti River in the Serengeti; the Great Wood of Caldedon, a vast area of old forest in the Scottish Highlands; California's undersea forests of giant kelp; a close-up view of the microscopic creatures that share one's home; a family of gibbons whose life style revolves around song; Africa's most successful large carnivore, the spotted hyena; a pride of lions in the Serengeti as a social group; and flamingos in the desolate Makgadikgadi salt pans of Botswana. Call (212) 769-5305 for more information.

Indonesia Month

Indonesia is a country of about 17,500 islands with traditions as rich and diverse as its many parts. Throughout April, a sampling of Indonesia's arts and cultures will be presented each weekend at the Leonhardt People Center, as well as Tuesday evenings in the Kaufmann Theater. Programs include the Javanese shadow puppet theater; the gamelan orchestra of metal gongs, flutes, xylophones, double-ended drums, and two-stringed fiddles; ancient ceremonial court music and dancing; *ikat* cloth making and the philosophy of batik garb; the cultures of the Asmat and Dayak peoples; and contemporary Indonesian arts in historical and cultural perspective. Anthropologist Clifford Geertz, writer Umar Kayam, and ecological anthropologist Christine Padoch will be among the speakers. All programs are free, and seating is on a first-come, first-served basis. For more information, call (212) 769-5315.

At the Planetarium

Join Mike Hauser, of the Goddard Space Flight Center, at the Hayden Planetarium on Tuesday, April 9, at 7:30 P.M., for a look at the origins of the universe and the creation of galaxies. Saturday, April 20, is National Astronomy Day, and the president and founder of the World Space Foundation, Robert L. Staehl, will talk about the science of solar sailing. For more information on daily Planetarium happenings, call (212) 769-5900.

Back to the Gobi

Last summer, three paleontologists from the American Museum retraced the Gobi Deset expeditions led by Roy Chapman Andrews in the 1920s. This first foray into an area closed to the Western world since 1930 (three more trips are scheduled) has already yielded exciting fossil finds from ecosystems of Central Asia that existed 100 million to 40 million years ago, including the bones of a seven-foot-long lizard related to the Komodo dragon of today. An exhibition of photographs and specimens from both the old and new expeditions will be displayed at the Museum this month.

Members' Programs

Yale archeologist Richard Burger will discuss the monumental architecture and complex societies of the ancient Peruvian civilizations at Cardal and Mina Perdida on Tuesday, April 9, at 7:30 P.M. in the Main Auditorium (admission is $5 for members; $8 for nonmembers). On Saturday, April 13, in the Kaufmann Theater, children will be able to explore the world of insects with Loveable Leroy, a bug puppet eight feet long ($5 for members; $8 for nonmembers). On Tuesday, April 16, at 7:30 P.M. in the Main Auditorium, anthropologist Helen Fisher traces Western concepts of gender from their earliest beginnings and makes predictions about male–female relationships in the future ($6 for members; $12 for nonmembers). Robert and Esther Tyrrell will talk about their two-year study of Caribbean hummingbirds at 1:30 P.M. on Sunday, April 21, in the Kaufmann Theater ($5 for members; $8 for nonmembers). For information and ticket availability, call (212) 769-5606.

These events take place at the American Museum of Natural History, located on Central Park West at 79th Street in New York City. The Kaufmann Theater and the Leonhardt People Center are located in the Charles A. Dana Education Wing. The Museum has a pay-what-you-wish admission policy. For more information about the Museum, call (212) 769-5100.

# The Milky Way

*East Indians have evolved a varied milk-based minicuisine*

by Raymond Sokolov

Speaking as a mammal, I'm not ashamed to say I think I belong to a fine bunch of vertebrates. Our 15,000-odd species contribute quite a lot to the happiness of the planetary biosphere. Even the hideous snouted spiny echidna of Australia, with its peculiar, not to say perverse, mating practices (which I'm not going to explain in a food column) is a welcome player on my team. We need all the help we can get. Mammals have been under siege lately—as predators and polluters—but the unkindest cut of all is the campaign aimed against our defining characteristic—milk.

As you will have guessed, I'm not about to turn traitor to my (taxonomic) class and join the antimilk Mafia. I concede that milk is a source of fat, of cholesterol, of allergenic proteins, not to mention a lot of substances the dietary gastrophobes talk about late into the night. Milk is also a source of such alleged poisons as cheese (a concentrated fat source with a potential for spreading various microbial plagues, including the uncommon but lurid listeriosis). Milk is, moreover, the source of artery-clogging cream and butter.

Millions of people simply can't digest milk after childhood. They lack an enzyme necessary for the successful metabolization of milk. Naturally, the cuisines of such groups do not include milk shakes. The question is: did these milkless cuisines produce the enzymeless adults or vice versa? And, more profoundly, should we in the precoronary set in the United States take these mostly African and Asian cuisines as models for our own consumption? Or does the temperate route make more sense for enzyme-endowed Americans, who also have easy access to skim milk, ice milk, and low-fat yogurt?

I confess that in my efforts to sail to the near side of obesity, I have tried all these dodges. But I do love dairy products, and I don't look forward to a long life made even longer by good dietary practice if that life abjures whole milk foods altogether. Lately, in fact, I've been looking into a previously unnamed category of recipes whose common ingredient is what might be called reduced milk.

Reduction is a standard procedure in cooking. The term comes up primarily in the context of French sauces; indeed, it is a translation of its French cognate, *réduction.* Escoffier will say "reduce by half and serve." He, and any other professional writer, means simply that we should boil a liquid until it is "reduced" in volume by half, through evaporation. Chefs reduce sauces to intensify their tastes and to thicken them. In the most extreme case, French *haute cuisine* reduces classic brown sauce so far that it is no longer a liquid but rather a solid meat glaze.

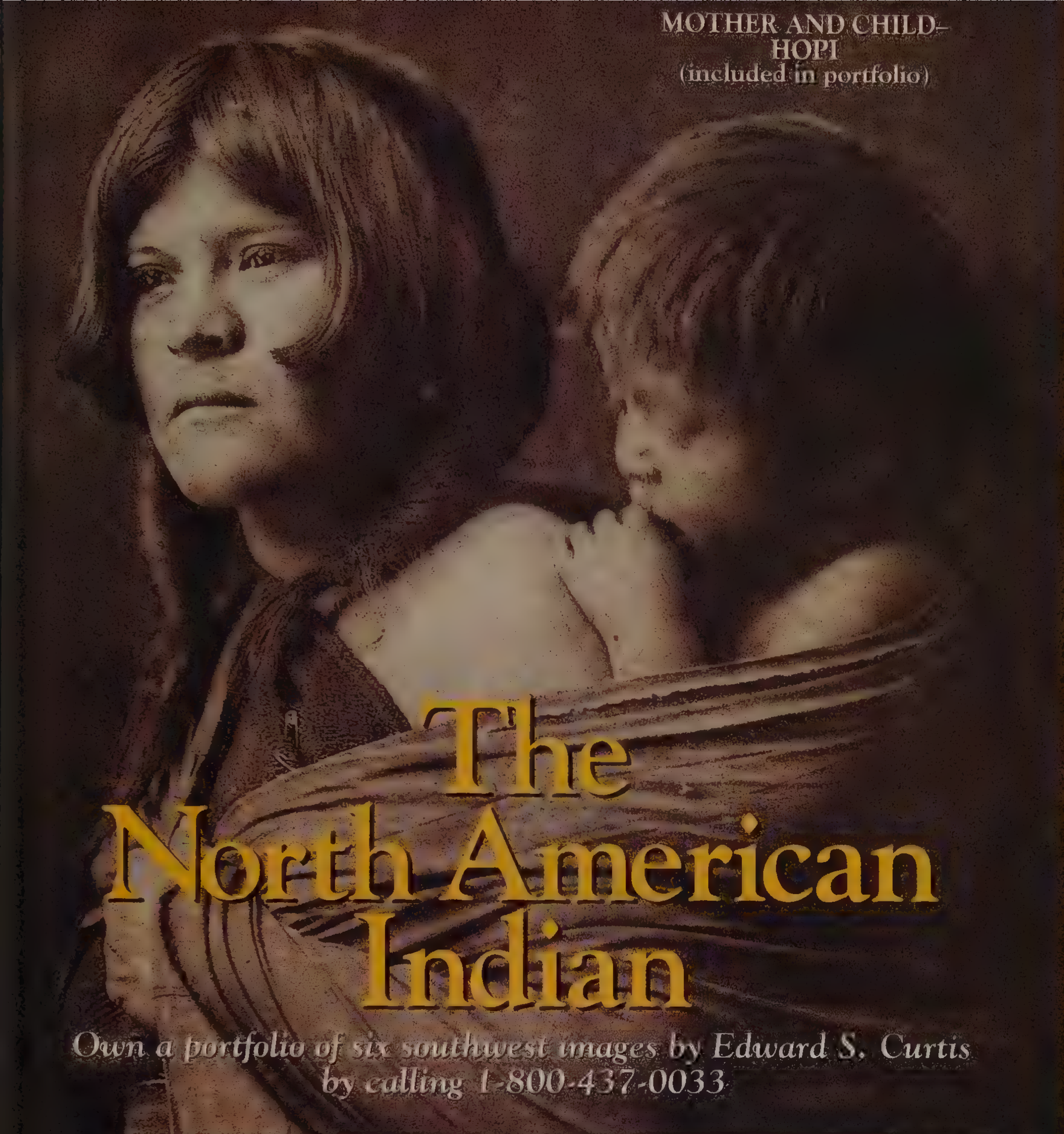
Milk also gets reduced in French cooking, most often in the form of cream. But all European cuisines share one recipe in which whole milk is reduced almost to nothing: rice pudding. A typical classic rice pudding recipe will combine a quart of milk with a quarter cup of rice. Slow cooking in an uncovered pan in the oven produces a solid and unctuous dessert. The disparity in the volumes of the milk and rice (the ratio of their volumes is 16:1) is so great that people reading a rice pudding recipe for the first time invariably conclude that the text has a misprint. Then a more experienced person explains to them that the rice has a miraculous ability to swell and absorb liquid.

This is also wrong or at least misleading. Yes, indeed, the rice absorbs a lot of liquid. Conventional recipes for plain boiled rice combine water and rice in quantities calculated to provide complete absorption of liquid just at the moment when slow cooking has softened the rice to the desired point of doneness. But the ratio of water to rice, by volume, is usually 2:1, never 16:1. And the cooking occurs in a covered pot, which almost completely eliminates evaporation or reduction of the liquid.

In other words, the absorbent capacity of rice is not a sufficient explanation of what happens with rice pudding. Obviously, that is a mixed case of absorption and of evaporation in an open container. Rice pudding raises questions because evaporation occurs after the rice has been added, making it hard to see what's happening. But we mustn't blame the first cooks who hit on this method, because they weren't interested in scientific demonstration. They wanted to find the easiest way to prepare rice pudding. And they knew that reducing milk all by itself, especially over direct heat, is a tedious and possibly messy business.

As anyone who has ever boiled milk has learned, milk traps steam as it is heated, and if the heating continues past a certain point, a small explosion occurs in the pan. The milk suddenly "foams up," as the cookbooks say, and overflows the pan. In order to overcome this problem when reducing milk over high heat, one should start off with a sufficiently large pan so that even foaming won't overflow the sides. After a while, when the milk has reduced and thickened, it becomes necessary to lower the heat very far and to keep stirring, both to prevent scorching and to stir back any skin forming on the surface of the milk.

Middle Eastern cooks carry this process to its ultimate. They reduce rich water-buffalo milk to a white solid called *eishta* in Arabic and *kaymak* in Turkish. When full reduction is done in the presence of sugar, the result is a coffee-colored, spreadable solid that plays a traditional role in Hispanic American desserts, especially in Argentina, under the name *dulce*

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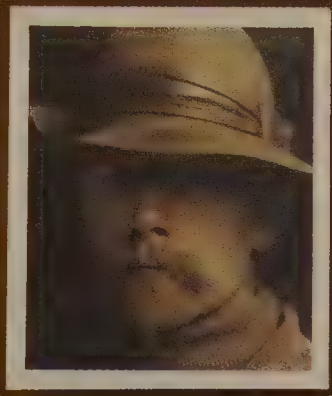

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*de leche*. In North America, we have evolved an informal, folk/industrial version of this dish: a can of sweetened condensed milk is completely submerged under boiling water until the sugar in it caramelizes and the milk solidifies.

In the Philippines, to the north of Manila, it is traditional to reduce the milk of the carabao, the local water buffalo, to a quarter of its natural volume and then to cook it with sugar until the mixture, still white, reaches the soft ball stage. Then these *pastillas de leche* are rolled in sugar and wrapped in white paper.

Reduced milk sweets reach their zenith as a genre in India. But then it is India, before all nations, that has experimented most completely with reduced milk. It is not an exaggeration to say that Indian cuisine contains within it a minicuisine evolved around the various stages of thickness that milk attains as its water evaporates, its proteins coagulate, and its natural sugars turn a gentle brown.

Milk is the major source of animal protein for the millions of vegetarian Indians and a basic component of the daily diet of most of the rest of India. Buffalo-milk yogurt, cheese, and the clarified butter called ghee are universal in Indian food, and in their Indian versions, they have special qualities setting them off from their non-Western analogues. The reduced milk dishes make up an even more special world.

Traditional slow boiling in an Indian wok, or *kadhai*, is a lengthy process made much easier and quicker in the microwave

**Braciole di Maiale al Latte**

Pork chops cooked in milk

(Slightly adapted from *Modern Italian Cooking*, by Biba Caggiano, Simon and Schuster, 1987)

*2 tablespoons unsalted butter*
*2 tablespoons oil*
*4 1-inch-thick pork chops, cut from the loin or the ribs*
*2 garlic cloves, lightly crushed*
*4 to 5 fresh sage leaves (do not use dried sage if fresh is not available)*
*Salt and freshly ground white pepper*
*¾ cup milk*

1. In a large skillet, heat the butter and oil until the butter foams. Add the chops, garlic, and fresh sage. Sauté the chops over medium heat until brown on both sides, about 5 to 6 minutes.
2. Season with salt and pepper. Add the milk. Stir to pick up the bits and pieces attached to the bottom of the skillet. Lower the heat and cover the skillet. Simmer for 12 to 14 minutes, turning the chops once during the cooking. If the milk evaporates completely during cooking, add a bit more.
3. Transfer the chops to a plate. Raise the heat and cook the sauce down until only a few tablespoons of thickened curds are left in the skillet.
4. Off the heat, remove as much fat as possible. Return the chops to the skillet and return to the heat. Cook briefly until the chops are well coated with the thick, browned milky sauce. Serve at once.

Yield: 4 servings

**Aab Gosht**

Lamb with milk

(Adapted from *Cooking of the Maharajahs: The Royal Recipes of India*, by Shivaji Rao and Shalini Devi Holkar, Viking, 1975)

*1 pound lamb, cut into 3-inch pieces*
*12 cardamom pods, slightly crushed*
*2 whole garlic cloves, peeled and slightly crushed*
*7 inches cinnamon stick*
*2 teaspoons salt*
*8 peppercorns*
*1 quart milk*
*¼ teaspoon ground ginger*
*¼ cup whole blanched almonds, unsalted*
*½ cup heavy cream*

1. Put meat in a heavy saucepan with water to cover. Bring to a boil and skim.
2. Add 4 cardamom pods, garlic, 3 inches of cinnamon stick, 1 teaspoon salt, and the peppercorns. Boil uncovered until the meat is tender. The water should be reduced to 1 cup. If not, remove the meat and reduce to 1 cup.
3. Meanwhile, in a separate saucepan boil and stir the milk over high heat with remaining cardamom, cinnamon, and salt until it is reduced to 2 cups.
4. Stir the lamb broth very slowly into the milk. Add the meat and the ginger and simmer, stirring for 10 minutes.
5. Purée the almonds with the cream in a blender. Just before serving, add this purée to the lamb. Heat the dish through and serve with white rice.

Yield: 4 servings

(as I observed last month in my discussion of Julie Sahni's *Moghul Microwave*), but the result is the same. Milk reduced to a quarter of its original volume is a light beige, aromatic liquid called *rabadi. Rabadi* reduced further, by half (to an eighth of the volume of the original whole milk), is a fudgelike solid called *khoya.* There are also many dishes where whole milk and a solid ingredient are cooked together until the milk is absorbed and almost vanishes, leaving behind a richness of texture and taste. One of the most unusual of these, showing the cosmopolitan side of Indian cuisine, is a spicy dish whose basic element is corn kernels cooked in milk until the milk "disappears."

*Rabadi,* the thick but still pourable reduction, makes a rich sauce for desserts and fruit. A cheese precipitated from *rabadi* is the basis for the dessert cheese dumplings, Bengali *ras malai,* and for the rich Indian ice cream *kulfi. Rabadi* rediluted with some regular milk is served as a beverage sweetened with sugar.

From solid *khoya,* Indians make a broad variety of fudges (*barfi*) flavored with pistachio, cardamom, ground cashews, coconut, potato, ginger, mung beans, semolina, and pumpkin. *Khoya* is cooked with grated carrots to make a moist pudding called *halwa.* The list could be extended because the Indian genius has applied the nutty richness of highly reduced milk to virtually every vegetable purée and flavoring. A particularly complex *khoya* dish is the pastry called *khoya poli,* in which a thin, fried whole-wheat puff (like the spherical bread called *poori*) is stuffed with a paste of *khoya,* grated coconut, sugar, sultanas, ground cardamom, chopped almonds, and rose water.

Perhaps the furthest that *khoya* cookery gets from a plain glass of milk is in the Kashmiri mock meat dish *matar shufta.* This is a vegetarian parody, as it were, of the ground meat and chickpea concoction called *keema matar.* For *matar shufta,* milk fudge grains are fried until they resemble ground meat.

Something like the same effect occurs in one of Italy's most celebrated dishes, *arrosto di maiale al latte,* pork roast with milk, in which a boned pork loin is braised in milk. Eventually, the milk reduces to the equivalent of *khoya,* and then it cooks further, in the pork fat, until it browns in nutty, meatlike, and very delicious little flecks. No one will believe it began as milk—except perhaps an Indian guest willing to indulge in pork.

*Raymond Sokolov is a writer whose special interests are the history and preparation of food.*

# Lady of the Flies

On a pleasant afternoon in East Africa's Serengeti Plain, a lioness takes her royal ease after a hearty lunch of antelope steak. No creature would dare to disturb—bzzzzt—or provoke the queen of beasts as she—bzzzzt—takes her rest. Well, almost none.

The squadron of winged invaders consists of ubiquitous East African pests known locally as Masai flies: insects that plague people and animals alike, particularly when they smell blood. As the lioness had apparently neglected to lick her snout clean after dining, dozens of flies were drawn to feed and lay their eggs on her carrion-smeared face.

This portrait of the feline monarch under siege was taken in Kenya's Masai-Mara Game Reserve by veteran wildlife photographer Boyd Norton. In 1989, he was cruising the plain in his Land-Rover near a spot where a leopard had draped an antelope carcass in a low tree on the previous night. His African guide believed the lioness had scavenged her meal from the leopard's day-old kill, which made her face particularly aromatic.

After expressing her annoyance, the lioness, in a belated bout of feline fastidiousness, dispatched her tormentors with a few swipes of her tongue.—*R. M.*

Photograph
by Boyd Norton

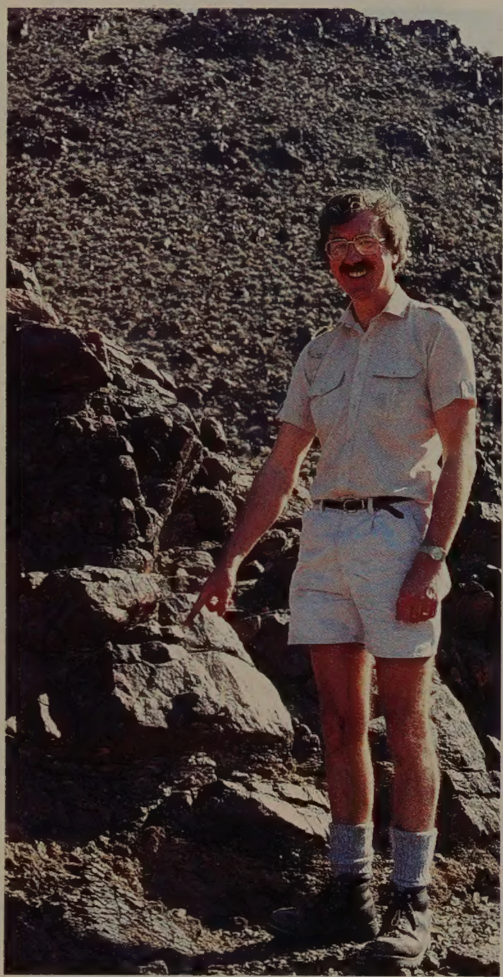
# AUTHORS

Transplanted Americans, **Patricia Vickers-Rich** and **Thomas H. Rich** (page 32) have been excavating fossils and teaching in Australia since the mid-1970s. Both studied paleontology at the University of California at Berkeley and earned doctorates in geology at Columbia University in New York. Interested in natural history "since at least four years of age," Patricia is now a reader in the earth sciences and biology departments at Monash University in Clayton, Victoria, while Tom is a curator of vertebrate paleontology at the Museum of Victoria in Melbourne. Sponsored by a variety of organizations, including the Australian government and the National Geographic Society, the Riches' fieldwork in southern Australia has been carried out with the help of hundreds of students and volunteers, many from Earth-

Fascinated by the "abrupt, often cataclysmic metamorphoses of marine sessile invertebrates," marine biologist **Christopher G. Reed** (page 40) specialized in the morphology and development of bryozoans, brachiopods, and polychaetes. Reed grew up on Vashon Island, in Puget Sound near Seattle, and developed an early, ardent interest in natural history. He was educated in his native state, earning both bachelor's and doctoral degrees in zoology from the University of Washington and doing fieldwork at the university's Friday Harbor Laboratories in the San Juan archipelago. In 1980 he came east for a postdoctoral fellowship at Harvard, and in 1982 he joined the Department of Biology at Dartmouth College in Hanover, New Hampshire. Known as a witty and enthusiastic lecturer who inspired students, at Dartmouth Reed twice received special recognition for distinguished teaching. Although bryozoans were his first love, Reed also enjoyed studying vertebrates and made many observations of skunks, raccoons, snakes, owls, and bats in the wild. After an extended illness, Christopher Reed died in January 1990 at the age of 38. He left a wife and an infant daughter. The Christopher Reed Memorial Fund, which assists student research at the Friday Harbor Laboratories, has been established at the University of Washington Office of Gift Policy, Seattle WA 98195.

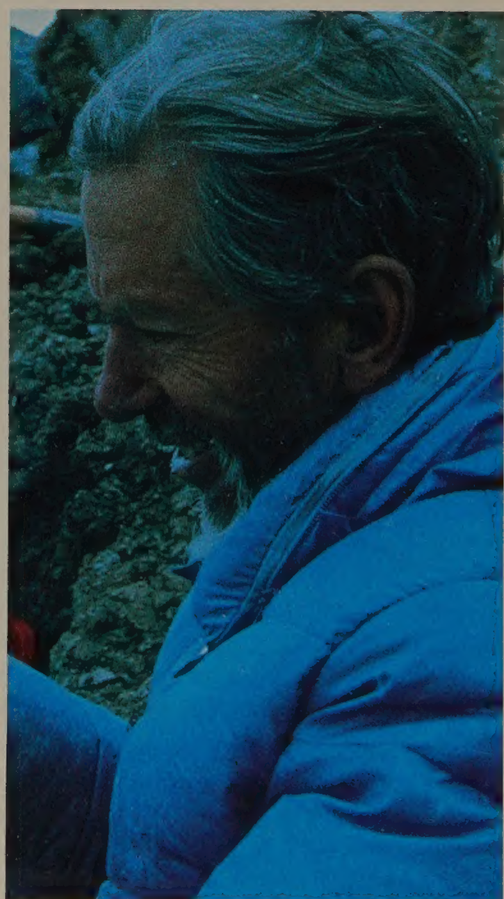
watch, who have, over the years, dug, blasted, and hauled tons of rock at Dinosaur Cove. The Riches have also brought an awareness of Australia's fossil history to the general public through television documentaries and educational programs. Authors and editors of many books, Pat and Tom Rich collaborated with Mildred Adams Fenton on a revision of *The Fossil Book* (New York: Doubleday and Company, 1989), an illustrated guide to prehistoric life. Australia's fossil record is the subject of *Kadimakara: Extinct Vertebrates of Australia,* edited by P. V. Rich and G. F. van Tets, illustrated by F. Knight (Princeton: Princeton University Press, 1990), and *Vertebrate Zoogeography and Evolution in Australia,* edited by M. Archer and G. Clayton (Carlisle, Australia: Hesperian Press, 1984).

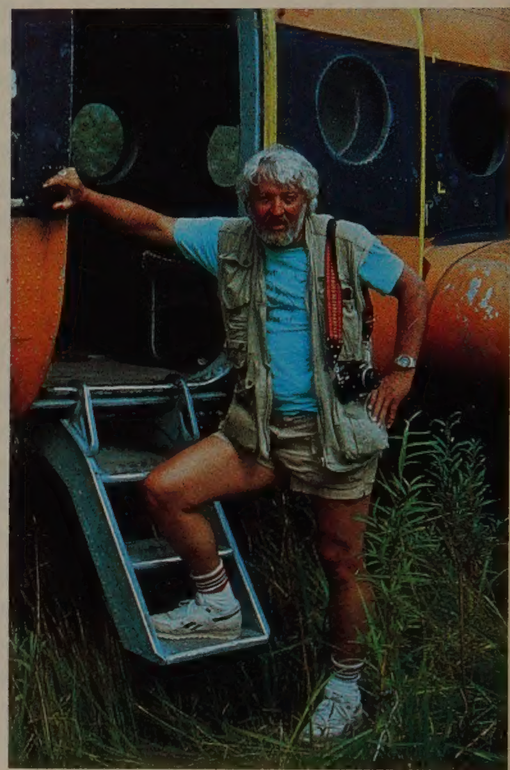
"Here is a difficult book I know I don't need anymore. Here, you take it," was what an archeology professor told **Joyce Marcus** (page 26) back in 1969, when she was a senior in college. The book in question was *An Introduction to the Study of the Maya Hieroglyphs,* written in 1915 by Sylvanus G. Morley. Since then, Marcus has avidly pursued the antecedents of Maya writing. Her other research concerns early villages and chiefdoms in Oaxaca, Mexico, and aspects of Maya political organization. Marcus is a professor of anthropology at the University of Michigan and curator of Latin American archeology at the university's Museum of Anthropology. For further reading she recommends *The Ancient Maya* (4th ed.), by Sylvanus G. Morley, George W. Brainerd, and Robert J. Sharer (Stanford: Stanford University Press, 1983); "Early Steps in the Evolution of Maya Writing," by Michael D. Coe, in *Origins of Religious Art and Iconography in Preclassic Mesoamerica,* edited by Henry B. Nicholson (Los Angeles: UCLA Latin American Center, 1976); and "Zapotec Writing," by Joyce Marcus (*Scientific American,* February 1980).



Standing in the desert in Oman, **Robert S. White** (page 50) points to the base of a slab of oceanic crust, which was shoved onto land when an ancient sea was caught between the earth's shifting plates. The site is one of the few places where geologists can observe oceanic crust from top to bottom. White has devoted most of his career to studying such crust, which forms two-thirds of the earth's surface. He went to the University of Cambridge as an undergraduate to study physics, but his love of the outdoors and the attraction of studying the geology hidden beneath the oceans (which was still largely unexplored) won him over to the subject of geophysics. Currently a geophysicist at Cambridge, White continues to study the earth's crustal structure and the interplay between tectonics and magmatism. For further reading, he recommends Robert and Barbara Decker's book, *Volcanoes* (San Francisco: W. H. Freeman and Company, 1989).

In 1964, shortly after he began his archeological exploration of the high mountains of northwest Argentina, **Juan Schobinger** (page 62) excavated the mummy of a twenty-year-old man on Cerro El Toro. Now he reports on a more recent discovery, the mummy of a young boy sacrificed by the Inca on Cerro Aconcagua, the highest mountain in the Western Hemisphere. A professor of prehistoric archeology at the National University of Cuyo, in Mendoza, Schobinger has also spent many years studying South American prehistoric art, especially the rock art of western Argentina. For additional reading, he recommends: *The Conquest of the Incas,* by John Hemming (Orlando: Harcourt Brace Jovanovich, 1973); *The History of the Incas,* by Alfred Metraux (New York: Schocken Books, 1970); *The Incredible Incas and Their Timeless Land,* by Loren McIntyre (Washington, D.C.: National Geographic Society, 1975); and *The Inka Road System,* by John Hyslop (Orlando: Academic Press, 1984).





On the morning of November 11, 1962, **Boyd Norton** (page 92) deliberately blew up a nuclear reactor—part of his job as a research physicist and technical director of reactor safety studies at the National Reactor Testing Station in Idaho. Nowadays, the only thing Norton blows up are his photographs; after a dramatic career shift in 1970, he has become a successful free-lance photographer and writer specializing in global environmental issues. He has photographed orangutans in Borneo, grizzly bears in the American wilderness, and a wide assortment of African animals in their native habitats. Norton is the author-photographer of nine books, his most recent being *The Mountain Gorilla* and *Boyd Norton's PhotoJournal,* a travel and field notebook for photographers. When he's not in the wilds of Borneo or Siberia or Africa, he lives in Evergreen, Colorado, with his wife, Barbara, two pet snakes, and, he claims, a piano-playing cat. To photograph the lioness for this month's "Natural Moment," Norton used a Leica R5 with a 400mm Leica Telyt lens. He prefers the softer light of slightly overcast days to capture subtle details of color and texture in portraits of wildlife.